**Identifying Groundwater Discharge Dynamics into Stream Habitat Assessments**
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## Abstract

Groundwater contributions are overlooked in many habitat assessments, even though their ecological and water quality importance to streams has been broadly recognized (Boulton and Hancock, 2006; Briggs and Hare, 2018; O'Driscoll et al., 2019). This lab encourages students to engage with a stream reach, consider how groundwater contributes to the study reach, and use methods to identify groundwater connectivity. We build on the concepts of EPA habitat assessment (Chapter 5) and ask students how human activities across the landscape may influence these stream ecosystems to explore policy improvements and additional considerations.

Groundwater's ecological relevance in streams and rivers is often thought of in three central ways: hydrologically (Brunke and Gonser, 1997), thermally (e.g. Sullivan et al., 2021) or chemically (e.g. Brookfield et al., 2021). Due to climatic and landscape changes, these relationships can be impaired and even become negative. As we explore the site, the students will be asked to consider this context and elaborate on potential scenarios that may influence how patchy groundwater discharge habitats, as well as stream ecosystems, may be disrupted through changes to the groundwater-surface water connection.

Overall, the goal of these lessons is to promote the inclusion of groundwater-dependent stream habitats into the river practitioner's toolbox, prompt discussion into positive, negative, and dynamic effects of groundwater contribution to the stream, and encourage discussion as to how to better include groundwater into the stream habitat assessment process.

## Instructor Notes

This lesson can be used independently or in conjunction with other River Scholar Lessons, notably Jones (2022) and Ward (2023).

Target audience level

This lesson can be modified for any level of education from undergraduate to professional and is designed to be used later within a semester-long hydrology, ecology, or natural resources entry level undergraduate course. A student's background should include understanding what groundwater is and how it can connect landscape to streams; however, this can be taught in a pre-lesson or can be previous knowledge. This lesson is designed to be differentiated by readiness, as not all methods and concepts presented within are required and can be taught modular. Prompts have been included to challenge advanced students to consider new contexts, processes, predictions, and skills throughout the lesson.

Summary of the lesson

The purpose of this lesson is to engage students to identify groundwater contributions to streams and consider the landscape context that could influence these groundwater inputs. A recommended pre-lab assignment would be to review Winter et al. 1998 (page 9- 17) (a foundational USGS publication on how groundwater and surface water are one resource), and through diagramming, summarize landscape-scale groundwater connects to streams.

The day of the lesson, a visual assessment will be conducted first and recorded as both text and sketch within each student's field notebook (time ~ 30 min). Consider the option to use sketch methods from Jones (2022). Second, students will collect data to assess groundwater contribution (time ~ 1-2 hours). This will include a water quality assessment to locate and evaluate groundwater contributions, and an option to perform differential stream gauging (two stream discharge measurements). Third, students will have the opportunity to reflect on these assessments, share data, consider the place-based context of the results, and consider ways to inform stream policy and management (time ~ 30 min).

This lesson is meant to encourage conversation on how the human impact on the groundwater can influence stream systems; direct and indirect. This greatly varies based on place, and how water resources are used by humans in that place, emphasizing the importance both contemporary and historical interactions. Below is a list to help instructors consider human impacts on groundwater resources that could influence streams. This is by no means exhaustive, but can provide a good starting point for most study systems.

> Groundwater amount- groundwater withdrawal: lowering water table, modifying hydraulic gradient (both reduction and reversal), land subsidence, salt water intrusion (also sea level rise), climate change modifications to precipitation magnitude and frequencies (drought and flooding).
>
> Groundwater pollution- chemicals and nutrients (both contemporary and legacy/historical),
>
> Groundwater temperature - climate change influences temperature.

Student context factors

The general interest of the students should be how landscapes influence stream water quality and ecosystem health. The goal of this lesson is to tune student's perspective on streams to consider groundwater influence, how groundwater may influence stream ecosystems, and how groundwater can connect landscapes to streams.

Approach to Engagement

This lesson engagement centers on the 5E model - engage, explore, explain, elaborate, evaluate. **Engage** students through the initial prompts of considering past knowledge, and previous experiences, with focus on what the landscape looks like through their travels to the site, and temporally through considering what the last few days were like weather wise. Focus on

engaging with our relationship with streams and our wider influence on stream water quality. **Explore** the landscape through observations and skills. **Explain** this will be done iteratively through encouraging students to ask questions of the lesson leaders, as well as from student collaboration. **Elaborate** through reflection and group discussion and connect landscape observations and knowledge to what was observed. **Evaluate** whether students use the skills and data collected to consider groundwater in stream quality and how to incorporate that into stream health assessment measurement protocol.

Equipment

Waders, field notebook, writing utensil, water quality probe with temperature and Specific conductance, and if available, Thermal Infrared Camera. Flow/current meter, measuring tape (length greater than stream width), tent stakes to secure measuring tape

**Learning Outcomes**

- Know key visual groundwater discharge indicators as well as measurable indicators.
- Explain the importance of groundwater discharge zones in habitat assessment
    - Describe situations when groundwater discharge could be positive for aquatic habitats and when they could be negative.
    - Interpret how these ecologically relevant zones may be threatened by human activities such as the addition of chemical contaminants and physical removal of groundwater.
- Contrast sampling design choices and their effect on summarizing groundwater contributions.
- Design a new standard operating procedure to improve stream assessment by including groundwater

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**Activity**

**Pre-lab (Optional)**

Using a Think-Pair-Share activity students consider how changes the landscape outside the riparian buffer can influence streams and stream ecosystems. First, students are asked to review Winter et al. 1998 (page 9 -17), and within one page of their field notebook creatively summarize (illustration or text) how the landscape connects to the stream. The intent is introducing how groundwater moves to a stream and should serve as helpful prompts during the field exercise. These summaries are intentionally open-ended but should aim to have the student understand the concept of groundwater flow paths connecting the land surface to streams. Then students pair up (virtually or in person) and compare and contrast the different concepts that stuck out to them and how they organized their thoughts.

**Lab Activity**

1. **A VISUAL-BASED HABITAT ASSESSMENT: Field Exploration and Sketch (30 min)**

    a. **<u>Site Initialization:</u>**
    - Record in field notes what landscape observation were made on the travel to the site, as text or visual imagery. Instructor Prompt: Considering the surrounding landscape, what activities may influence GW? Consider hydrologic, chemically, and thermally.
        - Human Activities
        - Topography
        - Other water bodies
        - General landscape
        - Consider temporal relevance: what has been occurring, yesterday, last week, last year, last decade?
    - Record initial conditions of the site - weather, time of day, initial impression of the site, important considerations from safety briefs.

    b. **<u>Site Exploration:</u>**

    Instructor divides study reach into segments based on number of desired student groups plus one additional segment for demonstration. On the demonstration segment the instructor should show generally what students could look visually that could be important changes for stream habitat. Examples for instructor to focus on could be through stream bank geomorphology (slumping, sinuosity, soil moisture), sediment type, organic matter size and presence/absence, riparian vegetation changes. The idea is to get students to identify patterns and anomalous features within a stream reach and the potential influence on stream habitat. After the demonstration divide students into small groups, exploring the stream reach visually.

    - They should identify portions of the reach that exhibit unique characteristics that **<u>may</u>** indicate groundwater discharge, sketch observations and/or take pictures of at least two of these locations. After exploration, **perform a timed 15-min overview sketch of the reach**, that focuses on patterns and anomalous features they identified (groundwater or otherwise).

*Instructor Note: Visual cues for groundwater discharge include isolated areas of increased soil moisture, increased bank slumping, rock fractures/joints, iron-staining, increased grain size, sediment movement (sand boils), physical flow, topographic change (toe of slopes), changes to type of vegetation, and in cooler weather can note locations of greener vegetation and no snow/ice. Often tree roots provide locations of strong groundwater discharge.*

*Figure 1: Examples of visual groundwater discharge indicators. From left to right, top to bottom: fractures with sediment, increased soil moisture above stream waterline, ochre floc/ oxidized iron near the base of a tree, anomalous stream bank slumping, ochre floc/ oxidized iron near concrete fracture joint.*

## 2. QUANTITATIVE MEASURES TO THE HABITAT ASSESSMENT: Water Quality

**Groundwater Dependent Ecosystem Indicator Water Quality Survey**
Time: 1 – 2 hours

Within the study reaches have the students use available water quality probes, infrared camera, handheld thermometers to complete the following assessment.

- Conduct both a longitudinal profile and point measurements of "areas of interest" using field notebook or field quality data sheet (example in Appendix A)
    - (i) Temperature
    - (ii) Specific Conductance
    - (iii) Dissolved Oxygen
    - (iv) Additional parameters as available (e.g. nitrate, contaminants)

The longitudinal profile can be collected as point measurements of the probe water quality parameters (temperature, specific conductivity) every 10-25m along the stream banks depending on the stream width and instructor intentions. If conducted with a thermal infrared thermometer,

this work should be done when the highest contrast between surface water and groundwater exists, focusing on detecting thermal anomalies along the stream bank (see Hare et al., 2015) for best practices of identifying groundwater discharge using infrared). This work can also be done using drone thermal infrared surveys as an alternative (see Briggs et al., 2019; Harvey et al., 2019 or MPART workgroup ).

The "areas of interest" can be assessed through visual cues identified by the students and by water quality changes in the longitudinal survey. Groundwater is often represented by high specific conductance, low dissolved oxygen, but that is a very broad generalization, please consider your site conditions and groundwater connectivity.

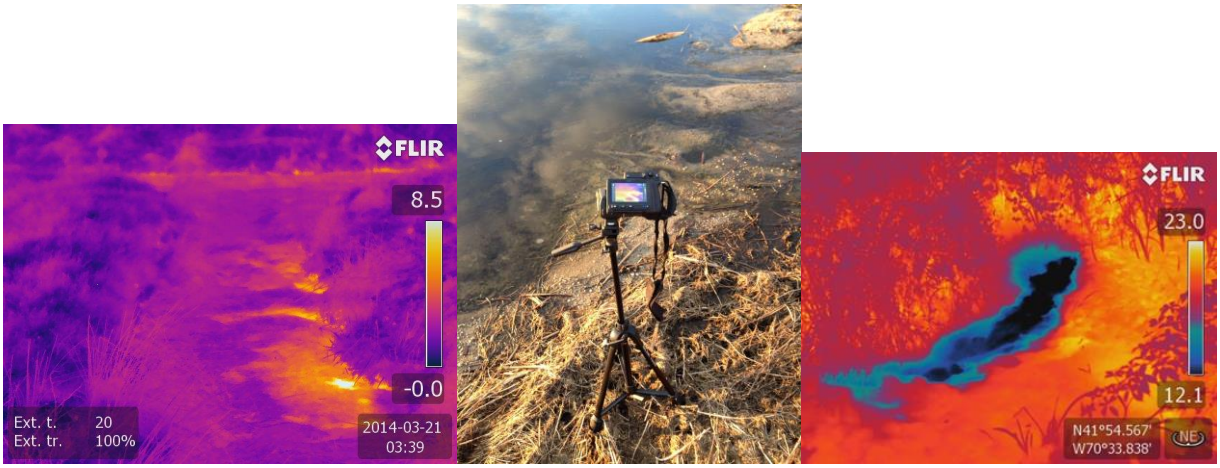


*Figure 1: (A) Example of infrared imagery of winter groundwater discharge, (B) infrared camera on tripod, (C ) infrared imagery of summer groundwater discharge.*

**Optional Additional Activity: Differential Gauging (2 transects)**

*Equipment needed: flow/current meter, measuring tape (length greater than stream width), tent stakes to secure measuring tape, field notebook/activity sheet.*

Have each group perform two streamflow transect using the USGS midsection method (see Jones (2022) lesson). These transects should be greater than 100m apart (the longer the better), and record results and calculations using the Jones (2022) lesson geomorphic datasheet worksheet (Part 4: Discharge Measurement). Each student should record the final streamflow for each of the two transects and subtract the downstream reach from the upstream reach to evaluate the flow volume gained over that reach.

*Instructor Note: Should have an error discussion that best streamflow tools and techniques have ~5% uncertainty; therefore, for GW gains to be realized via this method, 10% volume of the water needs to be gained over the evaluated reach - not reasonable for <100m reach scale studies.*

## 3. REFLECTION OF GROUNDWATER DEPENDANT ECOSYSTEMS

Each student data collection group should share all data for all members. After each member has all collected data within their field notebook, then new groups should be formed where one member from each data collection group combine to make small groups. Within these groups, the objective is to discuss the following list of questions that are interesting/relevant within the context of the observed results and place, and afterward discuss required responses below.

- What are the most useful ways to identify GW discharges to streams?
- What was surprising about the results?
- Visually, were there any unique characteristics about GW locations compared to other habitats within the stream?
- Chemically, what were the differences between locations with GW discharge?
- Did your visual observations and chemical results align with differential gauging?
- When might groundwater discharge be a net negative for stream ecosystems?
- What human activities influence groundwater dependent ecosystems?
- What types of samples may indicate impaired water qualities?

**Required Responses for Final Reflection Report:**

(1) How would your knowledge of groundwater discharge zones encourage you to modify macroinvertebrates sampling design and other benthic sampling strategies?
(2) How might these groundwater locations be resistant to or vulnerable to climate and landscape changes?
**(3)** Update the EPA Habitat assessment field data sheet, by adding a habitat parameter for consideration of GW discharge

**HABITAT ASSESSMENT FIELD DATA SHEET—LOW GRADIENT STREAMS (FRONT)**

| | | |
|---|---|---|
| STREAM NAME | LOCATION | |
| STATION # _____ RIVERMILE _____ | STREAM CLASS | |
| LAT _____ LONG _____ | RIVER BASIN | |
| STORET # | AGENCY | |
| INVESTIGATORS | | |
| FORM COMPLETED BY | DATE _____<br>TIME _____ AM PM | REASON FOR SURVEY |

| | Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|---|
| | | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| luated in sampling reach | **1. Epifaunal Substrate/ Available Cover** | Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient). | 30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale). | 10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed. | Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking. |
| | **SCORE** | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |
| | **2. Pool Substrate Characterization** | Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common. | Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present. | All mud or clay or sand bottom; little or no root mat; no submerged vegetation. | Hard-pan clay or bedrock; no root mat or vegetation. |
| | **SCORE** | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |

**Student Assignment for Assessment:**

Part 1: Copy of field notes, which must include initial field sketch and data collected
Part 2: Reflection Report (~ 1 – 2 pages), which includes:

- Updated EPA Chapter 5 Field Data Sheet row(s) to consider groundwater
- Summary text with at a minimum including:
    - How would knowledge of groundwater discharge zones modify macroinvertebrates and other benthic sampling strategies?
    - How might these habitats be resistant to or vulnerable to climate and landscape changes?

| **Assessment Rubric** | **Exemplar** |
|---|---|
| **Foundational Scientific Understanding: Interprets the basic components of groundwater connectivity in a stream context** | Shows a logical understanding of groundwater and surface water connection, and can describe the underlying principles within the direct connection and stream ecological relevance of groundwater discharge. |
| **Evidence and Observations: Creates useful and context-oriented field notes and sketches** | Keen sense of field detail and organization of thoughts and observations, while demonstrating context-based understanding of the larger picture |
| **Cross-disciplinary considerations: demonstrating the intersection between ecology, hydrology, and societal concepts** | Transforms original 'textbook' solutions, and demonstrates innovative, cross-boundary thinking while using scientific rigor and stream ecology foundational concepts. |
| **Applied Translation and Transformation: Shows consideration for translating field observations and concepts into policy and management derivatives** | While understanding the limitations of broad-scale management, demonstrates creative thinking and promotes evolution of ideas and methods. |
| **Voice: Demonstrates growth in their voice as a scientist** | Displays scientific interest with a collaborative spirit, willingness to consider multiple views and demonstrates creative questions and theories |

**Further Reading and Resources for Instructors (or interested students)**

Briggs, M.A., Hare, D.K., 2018. Explicit consideration of preferential groundwater discharges as surface water ecosystem control points. Hydrol. Process. 32, 2435–2440. https://doi.org/10.1002/hyp.13178

Boulton, A.J., Hancock, P.J., 2006. Rivers as groundwater-dependent ecosystems: A review of degrees of dependency, riverine processes and management implications. Aust. J. Bot. 54, 133 144. https://doi.org/10.1071/BT05074

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Harvey, M.C., Hare, D.K., Hackman, A., Davenport, G., Haynes, A.B., Helton, A., Jr, J.W.L., Briggs, M.A., 2019. Evaluation of Stream and Wetland Restoration Using UAS-Based Thermal Infrared Mapping 1–13.

O'Driscoll, M., DeWalle, D., Humphrey, C., Iverson, G., 2019. Groundwater Seeps: Portholes to Evaluate Groundwater's Influence on Stream Water Quality. J. Contemp. Water Res. Educ. 166, 57–78. https://doi.org/10.1111/j.1936-704x.2019.03302.x

Sullivan, C.J., Vokoun, J.C., Helton, A.M., Briggs, M.A., Kurylyk, B.L., 2021. An ecohydrological typology for thermal refuges in streams and rivers. Ecohydrology 1–15. https://doi.org/10.1002/eco.2295