PUTTING STREAM DEPTH DATA TO WORK

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1. Introduction

The Stroud Water Research Center developed the Mayfly Data Logger to reduce the cost of sensor-based monitoring of streams. Initially the device was shared with the broader research community, which adopted it for various applications across the United States. Over time the project has expanded to facilitate STEM education, citizen science, community-driven innovation, environmental modeling, and data sharing. One of the end goals is for environmental advocates collecting stream data using Mayfly data Loggers to communicate results to local government officials to facilitate conservation activity.

The Mayfly Data Logger is typically coupled with a sensor which is submerged in a stream and measures conductivity, temperature, and water depth. The Mayfly Data Logger coupled with this, and sometimes additional sensors, has become a valuable tool for environmental monitoring and education. As with any "tool" the usefulness depends on the knowledge of the user. The purpose of this document is to provide information and references to help establish knowledge regarding stream depth. Refer to Stroud's "Tools for Engaging with Municipalities and the Public on Freshwater Issues" for additional resources to understand stream temperature, stream conductivity, and engaging with municipal leaders.

Water depth is a fundamental parameter in assessment of stream health as well as an indication of its current level of hydraulic activity, such as riverbank erosion, turbulent flow, scouring and deposition, and bank full discharge- when the stream fills its channel beyond its capacity. Since it is an indicator of the volume of water flowing through a stream at any given time, water depth can provide significant information regarding overall stream health and the organisms that inhabit it. Water depth can influence temperature, dissolved oxygen levels, and habitat availability for aquatic life.

Water depth can also be an indicator of stream flow dynamics. In healthy streams, depth can vary seasonally and in response to rainfall events, reflecting a dynamic and responsive ecosystem. However, if a stream's water depth is consistently low or high, it could indicate issues such as drought or flooding, respectively. These conditions can stress aquatic life and lead to a decline in stream health.

Also, a 'flashy' stream, one that exhibits significantly increased flows immediately following the onset of a precipitation event and a rapid return to pre-rain conditions shortly after the end of the precipitation, can lead to flooding and/or erosion of the stream banks and washout of aquatic organisms. For additional information refer to "Stream Hydrology"

It is important, however, to note that while water depth is a valuable indicator of flow, flow is just one of many factors that contribute to stream health. Other factors, such as water quality (e.g., levels of pollutants or nutrients), temperature, the presence of riparian vegetation, and the diversity of aquatic life, also play crucial roles. Therefore, stream flow as inferred by depth should be considered in conjunction with these other indicators for a comprehensive assessment of stream health. It is the interplay of these factors that determines the overall

health and resilience of a stream ecosystem. For tips on how to identify a healthy stream refer to "How to Identify a Healthy Stream".

2. Understanding water depth

A. What is water depth?

Simply put, water depth is a linear measure from the bottom of the stream channel to the water surface. Although this seems simple on the surface (no pun intended) it can be challenging to ascertain. The bottom of a stream is rarely level and there may be significant variation between a measurement taken close to one side of the stream versus the opposite bank. This is particularly true if the measurement is taken at a bend in the stream. The U.S. Geological Survey (USGS) recommends that the stream stretch chosen for the measurement of discharge should be straight (no bends), at least six inches deep, and should not contain an area of low flow such as a pool. The Environmental Protection Agency (EPA) document "5.1 Stream Flow" contains more in-depth instruction on how to measure and calculate stream flow.

B. Water depth and its role in stream hydraulics

Stream hydraulics refers to the behavior of flow in natural streams and rivers. It involves understanding the physical principles governing the movement of water, including concepts such as flow velocity, pressure, and resistance. Hydraulic depth (D) is defined as the cross-sectional area of flow (A), divided by the top width of the flow (T) (see Eq. 1). Hydraulic depth, often used in computing the surface behavior and wave action, is an important parameter in stream hydraulics. Refer to the on-line continuing education course, "Introduction to Stream Hydraulics" for more in-depth discussion and diagrams that illustrate stream dimensions and relationship to flow.

$$D = A \div T \ (Equation\ 1)$$

Stream discharge refers to the volume of water that flows through a stream or river channel over a specific period of time. It is usually expressed in units such as cubic feet per second (cfs) or cubic meters per second (cms). The volume of water flowing through a stream is a function of multiple factors, including stream width and (average) depth. Calculating discharge through the stream is discussed in detail later in this document. In simple terms, water depth is therefore a factor in calculating the volume of water that the stream can carry at any given time.

Variations in depth can influence flow patterns. For instance, at shallow depth larger rocks on the streambed may protrude above the water surface, resulting in oxygen being entrained into the disrupted flow. Conversely, at high flows and deeper depth, upstream sections of the stream may be scoured, resulting in suspended sediment deposited between the submerged rocks.

In summary, water depth, and related parameters of volume, velocity, and discharge, are crucial factors that influence the stream hydraulics and the overall behavior of the stream. It is important to note that water depth and related parameters can change over time due to

numerous factors such as rainfall, snowmelt, and changes in the landscape such as loss of riparian buffer or deforestation. Channel depth can also change over time due to erosion increasing channel depth or sediment deposits reducing channel depth. More detailed explanations related to the hydrology of streams can be found in the "Natural Stream Processes", a publication of the North Carolina State Extension .

C. Physical variations affecting stream depth

1. Geography (mountains vs. plains)

Stream depth is influenced by geographical features. In general, as streams flow from mountains to plains, they widen and slow down due to a decrease in slope gradient, collecting more water and sediment from tributaries along the way. This sediment deposit reduces channel depth but in turn forces the stream to have a broader width to accommodate the required volume. Streams may meander more in flatter terrains with the decrease in gradient resulting in a decrease in depth.

The volume of flow, stream gradient, channel composition, and sediment type all act together to control sediment load (the magnitude of sediment in suspension and carried by the flow). The sediment load affects the stream channel depth by accelerating bank erosion during high velocity periods or dropping suspended solids when the velocity decreases. Steep streams carry high sediment loads, creating braided patterns with narrow channels, while streams in flat floodplains carry finer sediments and develop sinuous patterns, with the channel meandering with many curves and turns.

These variations in stream development dynamics make it apparent that determining channel depth requires more than taking one or two readings with a staff gauge. The stream channel can be significantly different across its length and numerous measurements need to be taken to properly characterize the shape of its cross section.

It is also important to note that the channel can be significantly different across time, particularly for lower gradient areas with larger floodplains. Over time, streams shape their drainage basins into smooth profiles by reducing steep gradients in upper reaches through erosion and filling in low areas in downstream reaches through deposition. This "shaping" impacts land surface more than glaciers, waves, or wind. Additional information regarding geography and its impact on streams is discussed in more detail in LibreTexts Geoscience website, "Stream and Rivers".

2. Stream Order

There is a relationship between stream order and stream water depth. Stream order is a method used to classify the hierarchy of streams and rivers within a watershed. This system, developed by hydrologist Robert E. Horton in 1945 and later refined by Arthur Newell Strahler, helps in understanding the structure and network of river systems.

First order streams are the smallest streams with no tributaries. They are usually found at the headwaters and are often ephemeral or intermittent, flowing only during wet periods. In some conventions, the portions of headwaters that develop during rain events can be referred to as zero order streams.

Second order streams are labeled as such because they are formed by the confluence of two first-order streams. They tend to be slightly larger and more consistent in flow compared to first-order streams. Continuing this pattern, a third-order stream is defined by the confluence of two second-order streams, and so on. As the order increases, streams become larger and more stable. Stream order plays a significant role in the hydrology and ecology of the watershed.

Stream order and stream water depth are related. First to third-order streams are usually found in the upper reaches of a watershed where stream water depth is usually shallow, and the streams tend to be narrow and have faster-moving water, especially in steep terrains. Water depth is greater for fourth order and higher streams. They are often located further downstream, and usually have larger drainage areas, resulting in more substantial water flow with wider channels. The increased water volume and lower gradient contribute to the greater depth of higher-order streams. As streams merge and their order increases, the volume of flow increases, resulting in deeper channels and a corresponding increase in depth.

In summary, depth increases with stream order due to the cumulative effects of larger drainage areas, increased flow volume, and sediment dynamics.

The article "What is the difference between a river and creek", by the Enviroliteracy Team, further explores this topic.

3. Substrate composition (bedrock vs. sediment)

a) Bedrock

Stream bedrock refers to the solid rock layer that lies beneath the loose sediments, soil, or unconsolidated material at the bottom of a stream or river channel. Bedrock forms the foundational structure of the streambed and significantly influences channel shape, flow patterns, and overall stability.

Bedrock substrates significantly influence the size of a stream and the subsequent water depth by affecting sediment load, erosion rates, and cross-section shape. Bedrock is typically more resistant to erosion relative to loose sediments. Streams with exposed bedrock tend to have more stable channels. The presence of bedrock can shape the stream's course, creating features such as rapids, waterfalls, and deep pools. Bedrock also influences how water flows through the channel, affecting turbulence and velocity.

An extreme example of bedrock impacting stream shape and depth is the Delaware Water Gap. The Delaware River flows through a 1200 foot deep, one mile wide, V-shaped notch in the narrow ridgeline of Kittatinny Mountain which consists of erosion-resistant bedrock.

Deformation of the bedrock during Appalachian mountain-building episodes hundreds of millions of years ago created an area of structural weakness in the rock. Erosion was concentrated in this weaker area, leading to the formation of the Gap.

When a stream or river encounters a narrow, resistant bedrock section, like the Delaware Water Gap, it can create a natural bottleneck. This can result in higher water levels upstream, as the flow is temporarily restricted by the narrowing of the channel. The water is forced to back up and rise before it can pass through the constricted area. Downstream, water levels may return to normal or even decrease slightly, depending on the flow and channel conditions. This effect is similar to what happens when water flows through a dam or a weir.

More details on geomorphologic features of a stream are available from the EPA in their Causal Analysis – Diagnosis Decision Information System (CADDIS) literature on "Physical Habitat".

b) Sediment

Stream sediment refers to the particles and materials that are transported and deposited by the flow of water in a stream or river. Sediment particles can range in size class from smaller (clay/silt) to larger (sand/pebbles/cobbles/boulders) These sediments can originate from various sources, including soil erosion, the weathering of rocks, and human activities such as construction and agriculture.

Water depth can be affected by stream sediment in several ways. If the streams' velocity slows due to a restriction to the flow, such as a dam, or an increase in stream width due to less steep stream banks, sediment can fall out of suspension and deposit on the stream bed. This will reduce the water depth.

On the other hand, if stream velocity increases due to a steeper stream gradient or an increase in stormwater entering the stream, sediment may be scoured off the stream bed by the faster flowing water and be carried away in suspension. This may increase the depth of the channel and result in an increase in the stream water depth.

More details on sediment in a stream are available from the EPA in their Causal Analysis – Diagnosis Decision Information System (CADDIS) literature on "Sediments".

c) Mayfly Depth Measuring Sensor and Stream Substrate

The Mayfly data logger instrument bundle is typically installed some distance above the stream bed, usually 3 to 6 inches. It is best to locate the instruments in an area where the substrate is bedrock, as bedrock is less likely to fluctuate due to sediment deposition or removal. Keep in mind that the stream water depth measured by the Mayfly reflects the depth of the sensor relative to the water surface. The discussion about substrate in the preceding paragraphs is more relevant to the stream water depth measurements taken when gathering data for determining the stream transects used to develop cross-sectional area of flow.

D. Climate variations affecting stream depth

Changes in water depth can be indicative of various potential health issues in aquatic ecosystems, often driven by both natural and anthropogenic factors. Several studies have highlighted the relationship between stream water depth variations and environmental health.

One significant factor is change in climate, which potentially alters air temperature and precipitation patterns, leading to changes in stream flow regimes. These changes can cause increased flooding or prolonged droughts, both of which can impact stream health negatively. For instance, decreased precipitation can reduce stream water depth, and coupled with increased air temperatures can lead to higher water temperatures. Higher water temperature is associated with lower dissolved oxygen levels which may result in stressing aquatic life and reducing biodiversity.

Human activities such as land use changes, dam construction, and water withdrawal for irrigation also impact water depth. Dams, while beneficial for water storage and flood control, often disrupt natural flow regimes, altering downstream flow and affecting sediment transport. This can result in habitat fragmentation and degradation of water quality, affecting the health of aquatic organisms. For example, studies have shown that dam construction and irrigation practices have significantly reduced stream flow in various regions, leading to decreased water levels and impaired ecological health.

Further, groundwater extraction for agriculture can lower water depth, especially in regions where streams and groundwater are closely connected. This interaction can lead to reduced base flow (sustained streamflow between precipitation and regulated by groundwater discharge to the stream) in streams, particularly during dry periods, further stressing aquatic ecosystems.

Overall, these changes in stream depth serve as important indicators of broader environmental issues, signaling the need for integrated water management practices that consider both human and ecological needs to maintain healthy stream ecosystems. Climate effect on streamflow is further detailed in the EPA article labeled "Climate Change Indicators: Streamflow".

3. Streamflow characteristics– riffles, runs, and pools

Streamflow characteristics include riffles, pools, and runs, which represent different flow velocities and stream water depths within a stream.

A healthy stream is often characterized by clear water and a steady, rapid flow. These shallow areas of steady flow are called riffles and are one important feature of a healthy stream. Healthy streams are dynamic (e.g., constantly adjusting to their surroundings) and should have a variety of features, not only areas with clear and rapid flow. Slightly deeper, straighter areas, known as runs, are where water moves slower. Areas with even deeper water depth are typically found where the stream bends. These areas are known as pools and are where the flow is barely perceptible, and the stream bottom may look a little murkier.

Riffles and runs help flush out sediments and facilitate the breakdown of nutrients that get into the stream. Pools, on the other hand, with their deeper depth and resultant slower velocities help trap sediments and nutrients so they do not get transported downstream too quickly. At a stream velocity of 0.3 to 0.69 meters (1 to 2 feet) per second, the stream is typically capable of transporting sediments without causing excessive erosion. This balance helps maintain a stable streambed and banks. Water moving at 1 to 2 feet per second helps with the natural aeration of the stream. A flow rate of 1 to 2 feet per second, along with the continuous sequence of riffle, run, and pool features, facilitates an even distribution of nutrients throughout the stream, ensuring that plants and microorganisms have access to essential resources. Additional stream related concepts and definitions are contained in the EPA's National Service Center for Environmental Publication (NSCEP) titled, "Volunteer Stream Monitoring: A Methods Manual"

4. Getting from stream depth to stream discharge flow - rating curves

Another important concept is the stream discharge; the volume of water that passes a given location within a given period of time. Imagine a river is like a busy highway. The "streamflow" is like counting how many cars pass a specific point on the highway every minute. If a lot of cars are moving by quickly, the streamflow is high. If only a few cars are passing slowly, the streamflow is low. Stream discharge is usually expressed in cubic meters per second (cms) or cubic feet per second (cfs).

This leads to the important concept of the stream rating curve (see Figure 3 below). The rating curve is a relation between stream depth and stream discharge. Each stream channel is different and because the stage-discharge relation is a function of the streambed material and geometry, each rating curve will be unique to that site and a particular period of time.

Channel depth is the starting point in generating a "stream depth to stream discharge" rating curve. The rating curve is a relation between stream depth and stream discharge. Once established, the rating curve allows you to determine volumetric flow (cms or cfs) by simply inputting the measured stream depth into the rating equation.

To begin developing the rating curve, channel depth must be measured at multiple points to compose a representative image of the cross-sectional area of the stream, also known as the transect. In streams with effective flow width between 3 and 10 feet, at least ten vertical measurements within the effective flow area of the transect are required. If the effective flow is greater than ten feet, a minimum of twenty vertical measurements should be obtained within the effective flow area of the transect. Note that the measurements extend beyond the current water level to account for future conditions when stream depth may exceed the level recorded at the time of measurement (see Figure 2 below).. Place an anchor such as a steel rebar driven into the ground, at both sides of the creek about one meter from the water's edge at the highest expected water level.

To determine stream discharge, you need to know the stream velocity along with the cross-sectional area of the stream. Imagine slicing a river like you would a loaf of bread. A cross-

section of a stream is likened to one of those slices. It shows you the shape of the streambed and the water flowing through it from one side to the other (see Figure 1). If you know the cross-sectional area of the water flowing through the stream, usually measured in square meters, and multiply it by the stream velocity, in meters per second, you arrive at the stream discharge in cubic meters per second. In other words, velocity multiplied by the cross-sectional area = discharge.

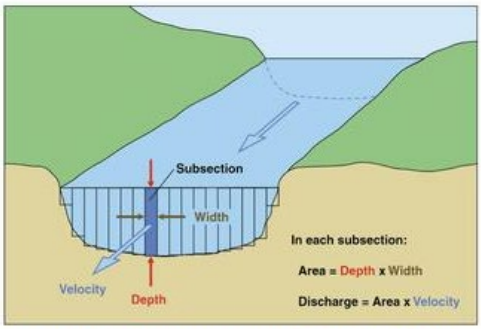

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Figure 1 – Stream Transect

One way to calculate stream velocity for a given section of the stream is to set up a start and stop point along the stream. Measure the distance between the start and stop point. Place a small, buoyant object on the water's surface and let it float down the stream. Time how long it takes the object to float between the start and stop point. Divide the distance by time to determine the stream velocity in meters per second. If available, stream velocity can be more accurately measured in situ with manual propeller or sonar flow meters.

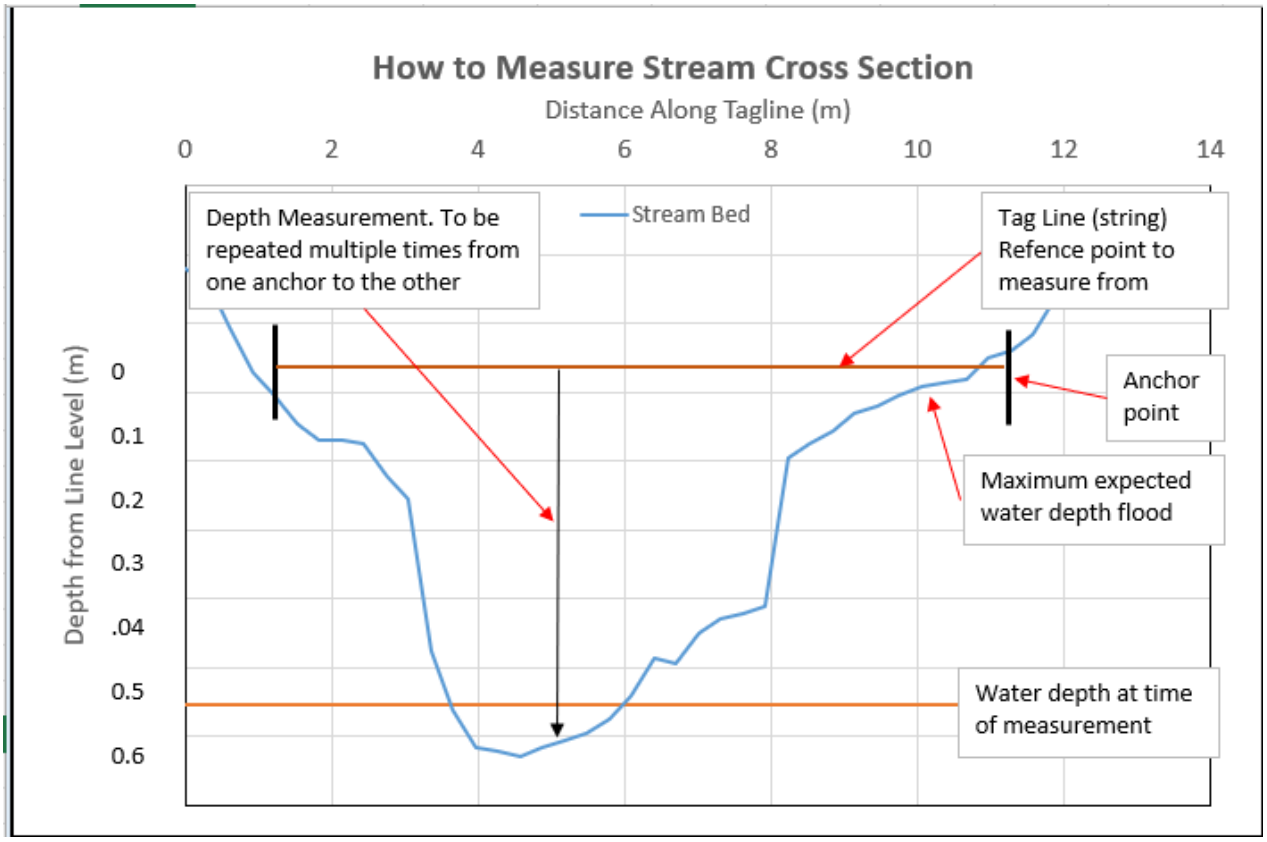

Figure 2 – Example from Stroud's spreadsheet

To assist in calculating streamflow at Mayfly sensor stations, Stroud has created a spreadsheet that is designed to predict the wetted cross-sectional area of a stream transect from the current stream depth, as indicated by staff gauge height or sensor depth. This value is needed to calculate the stream discharge. Regular measurements of discharge, in turn, allow the generation of a rating curve so that discharge can be continually calculated from stream height measured by an installed sensor station. The initial transect data should be generated based on measurements at the time of the Mayfly sensor station installation. After the "Transect Measurement" sheet has been fully filled out, it should not need to be modified unless the transect changes.

The next step is to measure the stream velocity as described above. This needs to be done multiple times when the stream is at different depths. This should be done for a minimum of five different depths.

Once this data has been collected, the rating curve is developed by multiplying the velocity by the cross-sectional area, which is the value obtained from the Stroud spreadsheet using the depth measured at the time the velocity test was done. This resulting value is the stream discharge.

Rating curves are developed over time. Each time a site is visited perform these steps: 1) measure velocity; 2) record water depth; 3) enter depth into Stroud spreadsheet to obtain wetted cross-sectional area; and 4) determine the stream discharge rate by multiplying wetted cross-sectional area by the velocity. After enough depth-discharge pairs are collected and plotted, a line is drawn through the points to describe the relation (see Figure 3).

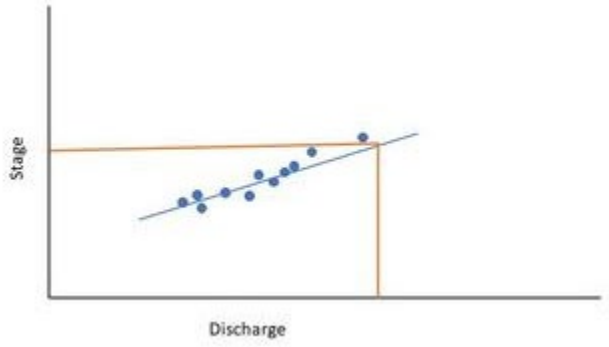

Figure 3

The rating curve can be used to estimate stream discharge simply based on the depth of the stream. This is significant because most water quality testing provides results in ppm (parts per million). To know the volume of a dissolved substance, for example chloride, transported by the water, we need to know the volume of the water flow at the time the water is tested, which is indicated by the steam discharge. For example, if we have 300 mg/L of chloride and the discharge is 0.07 cubic meter per second, or 70 liters/second (recall that 1 cubic meter is equivalent to 1,000 liters, 0.07 x 1000 = 70) that gives us 300mg/L x 70 Liters = 21,000 mg or 0.021 kg per second of chloride (recall 1,000,000 mg = 1 kg, 21,000/1,000,000 = 0.021), which does not seem like much. But considering that there are 86400 seconds in a day (60 x 60 x24 = 86,400) or 0.021kg x 86,400 = 1,814 kg (about 4,000 lbs) of chloride entering the receiving body of water per day!

Additional information, instructions on rating curves and access to the Stroud spreadsheet titled "Discharge Rating Curve Calculator" can be found here Supplemental Sampling, Rating Curves, Loads, Stroud Water Research Center. Additional information from the USGS can also be found here: Creating the Rating Curve.

5. Stream depth and its effect on stream health

Stream depth is a critical factor in determining stream health and the stream's overall impact on the ecosystem. Some of the potential positive impacts of steam depth on ecosystem health include the following:

- Habitat Diversity: Different depths create varied habitats, supporting a wide range of aquatic species.
- Temperature Regulation: Deeper pools help maintain cooler water temperatures, essential for temperature-sensitive species.

- Oxygen Levels: Shallow riffles enhance oxygenation, benefiting aquatic life that requires high oxygen levels.
- Refuge Areas: Deeper pools provide refuge for fish and other organisms during low flow periods.
- Nutrient Cycling: Depth variations contribute to the cycling of nutrients, supporting plant growth and maintaining ecosystem balance.

Stream depth can also negatively impact stream health and the ecosystem in several ways:

- Reduced Oxygen Levels: Deeper water layers may not mix well with surface layers, leading to hypoxic (low levels of oxygen) conditions.
- Channel Substrate Stability: Excessive depth can cause sediment deposition disrupting habitats.
- Temperature Fluctuations: Shallow streams are more susceptible to elevated temperatures, which can harm temperature-sensitive species and encourage the growth of harmful algae..
- Habitat Disruption: Imbalanced depth may lead to reduced biodiversity and negatively impact the ecosystem's health.

Maintaining natural variation in stream depth is crucial for preserving the delicate balance of stream ecosystems and supporting the continued delivery of vital ecological services.

While stream depth is a valuable aspect of stream health, it is a limited indicator and should be considered alongside other factors such as: water quality (chemical parameters like pH, dissolved oxygen, nutrient levels); temperature; hydromorphology, salinity, toxic contaminants; biological health (presence of pollution-tolerant species); riparian zone health (vegetation cover, bank stability); and flow regime (natural variations, human alterations). More information on this topic is available "Stream Flow and Volume - How much water is flowing in this stream?" from the Maryland Department of Natural Resources

6. Monitoring stream depth for stream health assessment

Measuring depth is essential for understanding stream health, flow patterns, and habitat conditions. Listed below are some common methods used to measure stream depth:

- Staff Gauge: A staff gauge is a simple, graduated ruler placed vertically in the stream. Observers can read the water level directly from the gauge. This method is straightforward and cost-effective but requires manual reading.
- Pressure Transducers: These devices measure the pressure exerted by the water column above them. The pressure data is then converted into depth measurements. Pressure transducers can provide continuous, real-time data and are often used in automated monitoring systems. The instrument bundles typically associated with the Mayfly Data Loggers utilize this type of technology.

Each of these methods has its advantages and limitations, and the choice of method depends on factors such as the required accuracy, available resources, and specific study objectives.

7. Human activities impacting stream depth

Some of the activities that can have a negative impact on depth include land use and water management. Earth moving operations, if not properly controlled, can result in soil ending up in streams and reducing water depth due to deposition. Improper water management, such as extracting large quantities of water for irrigation, water supply, or industrial cooling purposes can reduce depth to the point of having adverse environmental impacts. Improper storm water management can also lead to problems such as flooding and erosion. Unregulated land development, without allocating adequate open area or without compensating for additional impervious surface with stormwater retention/detention can lead to an increase in stormwater entering streams and causing a sudden rise in stream water depth and stream discharge.

On the other hand, there are activities which can have a positive impact on stream depth and contribute to the health of the ecosystem such as conservation and water management which has the goal of maintaining the natural depth of the stream. In addition, best management practices (BMP) such as stream bank protection and riparian buffers reduce erosion and sedimentation. Examples of BMP illustrations and descriptions and other stream geomorphology and hydrodynamic principles are available from the Natural Resources Conservation Service - Stream Restoration Planning, Fluvial System Stabilization, Field Guide.

8. Municipal engagement prompted by stream depth data

The trigger to engagement with a municipality from the perspective of this document is if stream depth is consistently low or high. A permanent stream that has dried up or an area that has recently been experiencing flooding should prompt action. Also, a flashy stream may indicate water is getting directed to a stream too quickly, perhaps from an increase in impervious surfacing in the municipality.

If you have a proposal for a conservation practice or solution, such as a rain garden, speak to your local governing body about it. Water depth monitoring may be a method to display that your solution is working. This is especially true regarding riparian buffer installation and any project that reduces impervious surfaces or slows the flow to the stream.

Municipalities are directly affected by environmental issues and have a unique role in promoting solutions. They are responsible for the operations, regulations, and resources within a given area, and responsible for the well-being of their populace, which are often tied to MS4 requirements. Municipalities also have a vested financial interest in maintenance of infrastructure such as bridges, roads, and storm sewer systems, which can be directly impacted by flooding events, eroding streambanks, or sedimentation that clogs stormwater drains. Therefore, they are often the best first point of contact for addressing local environmental concerns.

Municipalities vary in their powers, resources, responsibilities, and priorities based on factors such as demographics, budgets, and socioeconomic conditions. As a result, approaches to environmental issues may differ from one municipality to another. For guidance on how to report or discuss environmental concerns, consult your local municipal authority. In Pennsylvania, your county conservation district and the Penn State Extension service are excellent sources of information and technical support. If you are located outside Pennsylvania, similar organizations may be available in your state or region.

Influencing municipal leaders regarding environmental issues can be a complex task since every municipality is unique, so the approach might vary based on the specific context and the leaders you are trying to influence. It is always a good idea to understand the local political landscape and tailor your approach accordingly.

There are several points of leverage that can be used. In this regard, we cannot overemphasize the value of the corresponding workgroup document, "How to Engage with Municipal Leaders," which provides in-depth treatment of the subject.

9. References

Bengtson, H. (n.d.). Introduction to stream hydraulics [Online course]. CED Engineering. https://www.cedengineering.com/courses/introduction-to-stream-hydraulics.

Brooks, H. (2024, February 6). Tools for engaging with municipalities and the public on freshwater issues. Manage My Watershed. https://managemywatershed.org/engaging-with-municipal-leaders/

Delaware River Basin Policy and Practice Workgroup. (2024, February 6). How to engage with municipal leaders (Rev. 0). https://managemywatershed.org/wp-content/uploads/How-to-Engage-with-Municipal-Leaders.pdf.

Enviroliteracy Team. (2024, September 25). What is the difference between a river and creek? The Environmental Literacy Council. https://enviroliteracy.org/what-is-the-difference-between-a-river-and-creek/.

LibreTexts. (n.d.). Streams and rivers. Biogeochemistry. https://geo.libretexts.org/Bookshelves/Geography_%28Physical%29/BioGeoChemistry_%28LibreTexts%29/08%3A_Inland_waters/8.06%3A_Streams_and_Rivers.

NC State Extension. (n.d.). Natural stream processes. NC State Extension Publications. https://content.ces.ncsu.edu/natural-stream-processes.

Ruff, B. (2025, July 6). How to identify a healthy stream. wikiHow.life. https://www.wikihow.life/Identify-a-Healthy-Stream.

Sullivan, A. (2014). How does rainfall affect stream health? Maryland Department of Natural Resources. https://dnr.maryland.gov/education/Documents/HowDoesRainfall.pdf.

U.S. Department of Agriculture, Natural Resources Conservation Service. (2012, July). Stream restoration field guide. https://www.nrcs.usda.gov/sites/default/files/2024-10/Stream%20Restoration%20Field%20Guide_july%202012.pdf.

U.S. Environmental Protection Agency. (n.d.). 5.1 Stream flow. Monitoring & Assessment. https://archive.epa.gov/water/archive/web/html/.

U.S. Environmental Protection Agency. (2025, May 9). Climate change indicators: Streamflow. https://www.epa.gov/climate-indicators/climate-change-indicators-streamflow#:~:text=Climate%20change%20can%20affect%20streamflow,reduce%20streamflow%20in%20certain%20areas.

U.S. Environmental Protection Agency. (2025, June 1). Municipal Separate Storm Sewer System (MS4) Storm Water Management Program (SWMP). https://www.epa.gov/tx/municipal-separate-storm-sewer-system-ms4-storm-water-management-program-swmp.

U.S. Environmental Protection Agency. (n.d.). Physical habitat. https://www.epa.gov/caddis/physical-habitat.

U.S. Environmental Protection Agency. (n.d.). Sediments. https://www.epa.gov/caddis/sediments.

U.S. Environmental Protection Agency. (1997). Volunteer stream monitoring: A methods manual (EPA 841-B-97-003). National Service Center for Environmental Publications. https://nepis.epa.gov/Exe/ZyNET.exe/P100MRC3.txt.

Water Encyclopedia. (2008). Water Encyclopedia. The Gale Group Inc. http://www.waterencyclopedia.com/.

Wyoming-Montana Water Science Center. (n.d.). Creating the rating curve. U.S. Geological Survey. https://www.usgs.gov/centers/wyoming-montana-water-science-center/creating-rating-curve.