



Air, Water, and Aquatic Environments

Science Program



A Simple Method Using Underwater Epoxy to Permanently Install Temperature Sensors in Mountain Streams

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The need for annual stream temperature data

Thermal regimes are fundamental to understanding aquatic ecology, given the ectothermic physiologies of most aquatic organisms. Moreover, significant departures from historical conditions are underway in response to a warming climate (Isaak et al. 2010; Isaak et al. 2011, Kaushal et al. 2010; Rieman and Isaak 2010). Although considerable amounts of stream temperature data are now routinely collected using inexpensive digital temperature sensors, most of these data are collected during summer when temperatures are warmest and access to mountain streams is easiest. This provides a narrow view of thermal regimes in streams and misses ecologically relevant information about the date of spring onset, growing season length, overall variability, and total annual thermal units.

Collection of annual stream temperature data has traditionally required labor intensive instrumentation of permanent sites that often require steel cables or other obtrusive structures in streams and instrument loss rates can be high. These difficulties limit deployments of sensors for annual temperature data, despite the need for this information and potentially lower maintenance costs (i.e., site visits) once a permanent site is established. Ideally, a method for installing permanent temperature sensors would require minimal effort and materials, be largely foolproof, and provide durable installations that can withstand large annual floods in mountain streams. In addition, it would be desirable if installations were relatively innocuous so that the sensors were not stolen or otherwise vandalized during lengthy deployments. Here, we describe a protocol that fulfills these requirements by using underwater epoxy to directly attach temperature sensors to large rocks (i.e., boulders) in mountain streams.

Using Underwater Epoxy to Permanently Install Temperature Sensors

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Laboratory and field testing

A series of laboratory and field trials were used to assess several underwater epoxies (AquaMend[®] from Polymeric Systems Inc.; AquaStik[®] from DuPont, Waterweld from J-B Weld Company, Mr. Sticky's[®] Underwater Glue from Advanced Adhesion Inc., HIT-RE 500 from Hilti, Sea Goin' Poxy Putty from Permalite Plastics Corp, and A-788 Splash Zone Underwater Epoxy Putty from Carboline Company), before a product manufactured by Fox Industries (FX-764; see Appendix A for equipment list) was selected for use in this protocol (see details in Isaak and Horan 2011). In addition to adhesive properties that were usually far superior to the other test products, the putty-like consistency of the Fox FX-764 epoxy makes it easy to use in the field and attachments to rocks have proven secure when initiated under a range of temperatures (5°C - 20°C). FX-764 is available by the quart from the manufacturer, if requested, and can be transferred to smaller containers for field use (Appendix A). The Sea Goin' Poxy Putty and A-788 Splash Zone Underwater Epoxy Putty also formed strong bonds underwater but were considerably more difficult to work with in the field.

Numerous temperature sensors are commercially available, but we used the TidbiT[®] v2 Temperature Data Logger* (right) because of its compact size, large memory and long battery life (up to 5 years), a waterproof, durable casing, and because the sensors may be downloaded in the field using a portable data shuttle. The TidbiT v2 has an orange faceplate, in contrast to the older TidbiT v1, which has a yellow faceplate and is not compatible with the data shuttle.



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Necessary equipment

In addition to the sensor and epoxy, the following materials are partially what is needed for underwater epoxy installations (see Appendix A for a more complete list): (1) rubber gloves (to avoid skin contact with epoxy), (2) a wire brush to clean the rock surface prior to sensor attachment, (3) a plastic box to view the sensor underwater and ensure a good placement, and (4) metal forestry tree tags to monument the rock to which a sensor is attached (Photo 1). For enhanced visibility, we paint a small circle on the rock using high-performance industrial grade paint (RUST-OLEUM). A GPS, digital camera, and datasheet (Appendix B) are needed to geo-reference and photo archive the sites where sensors are deployed.

**mention of trade names does not imply an endorsement by the U.S. Forest Service*

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Preparation before going to the field

- **Calibration** Before installing temperature sensors in streams, calibrate the sensors in a common temperature environment as described in Dunham et al. (2005) and return sensors with anomalous readings to the manufacturer.
- **Solar Shield** The sensors should be outfitted with a shield so that sunlight does not strike the sensor and bias the temperature readings. We have experimented with two different shields:

Neoprene Flap

This type of solar shield can be constructed by attaching a small neoprene flap (3" x 3") to the top of the sensor with two exterior-grade plastic cable ties (Photo 2). Small weight attached to the front of the flap ensures that it hangs over the sensor to improve shading and helps to prevent turbulent flow from lifting the flap (Photo 3).

PROS: Neoprene shields have several advantages, including low cost, low visibility (it is rapidly colonized by periphyton to camouflage the sensor), and the sensor can be downloaded in the field using the underwater data shuttle.

CONS: The long-term durability of these shields is unknown at present, the sensor is vulnerable to damage from moving substrate, and if epoxy oozes up the side of the TidbiT during installation it may be difficult to download the data without having to scrape off excess epoxy.

PVC Canister

This solar shield has 3 pieces, including a flat, solid bottom and a screw-top cap (Photo 4). The 2 bottom pieces are glued together with PVC cement, and then several holes are drilled into these pieces to facilitate water flow (see Appendix). Wrap the threads of the cap with Teflon tape. A small piece of neoprene (1" x 2") is zip-tied to the sensor before it is placed inside the canister (to provide some cushion), and the entire unit is epoxied to a large rock.

PROS: A PVC canister will protect the TidbiT from damage and costs \$5 for materials typically available at local hardware stores. Downloading or replacing the sensor is easier with a PVC canister because the top can simply be unscrewed and the sensor removed. This system may be especially well-suited for long-term monitoring efforts because new sensors can be placed in the same PVC canister after the previous sensor expires. The PVC canisters could also house sensors that are not waterproof if the canisters are not drilled, but we generally discourage this practice because laboratory trials suggest a time lag between changes in water temperature and air temperature within a canister.

CONS: PVC solar shields are best suited to areas where human traffic levels are lower due to their visibility. Moreover, the canister is larger and slightly more difficult to attach to rocks.

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Sensor installation

Considerations regarding sampling designs, or where sensor sites are established across the area of interest, are beyond the scope of this protocol and are covered in more detail elsewhere (Dunham et al. 2007; Isaak et al. 2009; Isaak 2011). Here, we assume the user has already developed a sampling design to meet their needs and concern ourselves only with sensor deployment at an individual site.

1. At the site, search for a large rock or boulder (charismatic megaboulders are essential!) that will be immobile during large floods and is easy for others to identify on subsequent site visits. Concrete bridge supports also provide good attachment sites at some road crossings (Photo 5). Finding a good attachment site is **the most important part** of a successful epoxy sensor installation. If attaching to a rock, select only those large enough to protrude a foot or more above the low flow water surface and wide enough that they can effectively shield the sensor from moving rocks or debris during floods (the sensor will be attached to the downstream side). **Do not move rocks into the channel to serve as attachment sites** – if you can lift the rock, high flows will surely dislodge it, not to mention the safety risk associated with lifting large boulders.

Ideal site characteristics on the downstream side of your attachment site are pockets of relatively calm water with smaller substrate sizes. If large rocks and cobbles are on the downstream side, similarly large substrates are likely to move there again during the next flood and will probably dislodge or break the sensor. Finally, the attachment rock should provide a relatively flat downstream attachment surface that is deep enough to remain submerged and is in, or near, flowing water for the entire year.

Large substrates suitable for attachment may be relatively rare within low-gradient, meadow reaches, and in these instances, steeper channels immediately up or downstream of the meadow may have to be sought out or other deployment techniques should be applied.

Once a good attachment site has been located, perform the following steps, whether the sensor is being applied directly to the rock, or in a canister that's adhered to the rock:

2. If your sensor has an indicator light, check for the blinking that indicates the sensor has been launched and is ready to collect data. On the datasheet record the serial number of the temperature sensor and the metal forestry tag number.
3. Use a wire brush to clean the rock's surface where the sensor will be attached.

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Tip: put on rubber gloves before putting hands in water, otherwise, it's a struggle to get them on once your hands are wet.

Pick a location that is well below the water surface, but at least 2 – 3 inches above the stream bed to minimize the possibility that the sensor will be buried. If an underwater data shuttle will be used for data retrievals, at least 8 inches of space in the downstream direction from the sensor is needed for access. In addition, the angle of the mounted sensor must allow for the shuttle to be attached without interference by the stream bed. We suggest that you experiment with the shuttle and the sensor in the office to understand the angle needed to ensure a proper download.

Place a cobble-sized rock near the attachment site that you will use at the end of the installation to lean against the attached sensor while the epoxy hardens.

4. With gloved hands, wet your fingers, and grab equal parts of the Fox epoxy (one white, one grey). Manipulate the two parts together for at least 1 minute until the epoxy is a consistent color throughout (Photo 6). If the epoxy becomes tacky while mixing, re-wet your fingers and continue to mix it.

If gluing a sensor directly to a rock surface —

Apply enough epoxy to the back of the sensor that the surface is covered to a depth of approximately 1/8 inch (Photo 7). Apply the epoxy as a rounded glob in the center of the sensor so it can mold to the rock surface when pressed into place. Do not push too firmly or the epoxy may be pushed up the sides of the sensor, which could either block access with the underwater data shuttle or leave too little epoxy in place to establish firm adhesion (Photo 8). Make sure the sensor is mounted with the tab pointing upright (Photo 9). This allows the indicator lights on the underwater data shuttle to be seen during data retrieval so that the success of a download can be determined.

If gluing a canister to a rock —

Mix a batch of epoxy about the size of a golf ball. Apply enough epoxy so that it pushes up the sides of the canister and encompasses its lower lip, which will help hold the canister on the rock (Photo 10). Some underwater epoxies (including Fox FX-764) will not bond PVC to a rock, so it's critical that the bottom of your canister have a lip which the epoxy can wrap over.

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5. Use the plastic viewing box to see underwater while you push the sensor (or the PVC canister) onto the cleaned rock surface. Gently twist the sensor or canister back and forth to set it in place (Photo 11). If excessive amounts of epoxy block the sides of a directly attached sensor, use your fingers to trim away the excess and use less epoxy in the future. If you are not satisfied with the sensor or canister location, slowly remove it from the rock, rework and reshape the epoxy, and reattach it to the rock in the desired location.
6. Although the sensor may adhere to the rock during the initial application, it takes 24 hours for the epoxy to fully set (although it becomes progressively more stable each hour). Ensure it does not slide off the attachment point by gently leaning a small rock against the front of it (Photo 12). Do not support the sensor with a rock from below and make sure the leaning rock pressures the sensor directly into the attachment rock surface or it may loosen the initial adhesion. Re-check your installation with the viewing box and make a detailed examination of the contact seam between the epoxy and the rock surface. Make sure no gap has appeared and if it has, reseat the sensor and adjust the leaning rock as needed.
7. Use epoxy to glue a metal forestry tag directly above the sensor (or pointing toward it) and above the water line to make it easier to locate the sensor during a subsequent site visit. Attach the tag to the downstream side of the rock to prevent it from being scoured off (Photo 13). Lastly, you may wish to spray paint a circle or other mark on the rock to provide greater visibility from longer distances. Remember, it may be one or more years until the site is revisited (and it may be someone else who retrieves the data). If the rock cannot be relocated, valuable data will be lost.
8. Geo-reference the sensor location using a GPS and take several digital photos of the specific rock attachment site and immediate surroundings to aid in future relocation. Record the position of the sensor on the datasheet (e.g., sensor attached to grey, rectangular rock 1m in diameter along the left side of the channel) and create a digital archive of your field notes and photos for future reference. See Appendix C for a summary of these 8 steps. This procedure is demonstrated on **YouTube** (see page 10).

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Data retrieval

Temperature sensors should be visited periodically to retrieve the temperature data. One of the major advantages of permanent installations is that site visits can occur infrequently, perhaps once a year initially and less thereafter, as confidence is gained in the durability of a site installation. Data can be retrieved in several ways—either by using the data shuttle, by

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unscrewing the top of the PVC canister with the sensor, or by removing the sensor from the rock and downloading it in the office. Collecting a minimum of 2 – 3 full years of data at a site is desirable in many cases because the effects of contrasting climate years (i.e., seasonal or inter-annual differences in air temperature and stream flow) on stream temperature will be observed. Multiyear data can be used in inter-site comparisons of short-term temperature sensitivities or to develop longer-term historical reconstructions or projections based on relationships with air temperature and stream flow (Moatar and Gailhard 2006; Isaak et al. 2011; van Vliet et al. 2011). Better yet, however, are long-term temperature monitoring efforts that persist indefinitely into the future. Long-term temperature records on unregulated streams are extremely rare and we encourage you to help make sure that is not the case 20 years from now.

Downloading sensors using the data shuttle—

1. Before attempting to retrieve data with the data shuttle (this can be done above or below water), feel the front of the sensor to ensure the LEDs are still attached. Check that the sensor is still blinking, and thus, collecting data. If you cannot see the light, hold a metal mirror underwater next to the shuttle (you can buy the mirror at a camping supply store).
2. Press the shuttle firmly onto the TidbiT and then squeeze the black lever (Photo 14). If the shuttle is properly engaged, the amber light will start to blink as the data are downloading (Photo 14a). After the download is complete, the shuttle will re-launch the TidbiT with a blank memory using the same logging interval, and the green light will blink for 15 minutes (Photo 14b). You may remove the shuttle from the TidbiT at any time during this 15-minute period and squeeze the black lever to stop the green blinking.
3. If the shuttle is not engaged properly, the red light will blink when the black lever is pressed (Photo 14c). Remove the shuttle, reattach it, and try again. If the data download still does not initiate, gently clean the surface of the TidbiT and check to ensure that debris does not preclude proper engagement with the shuttle. If too much epoxy is present on the sides of the TidbiT, the excess may need to be chipped away with a screwdriver to ensure a proper fit with the shuttle.

Warning: do not change the shuttle's batteries in the field as this will stop the shuttle's clock and will prevent further downloads. Refer to the user's manual for more information.

4. The data shuttle has memory capacity sufficient for downloading 63 TidbiTs. The instructions for downloading, presented herein, are not meant to be all-inclusive. Users should consult the manual that accompanies the Onset Shuttle and practice using the TidbiT v2 and shuttle before taking them to the field.

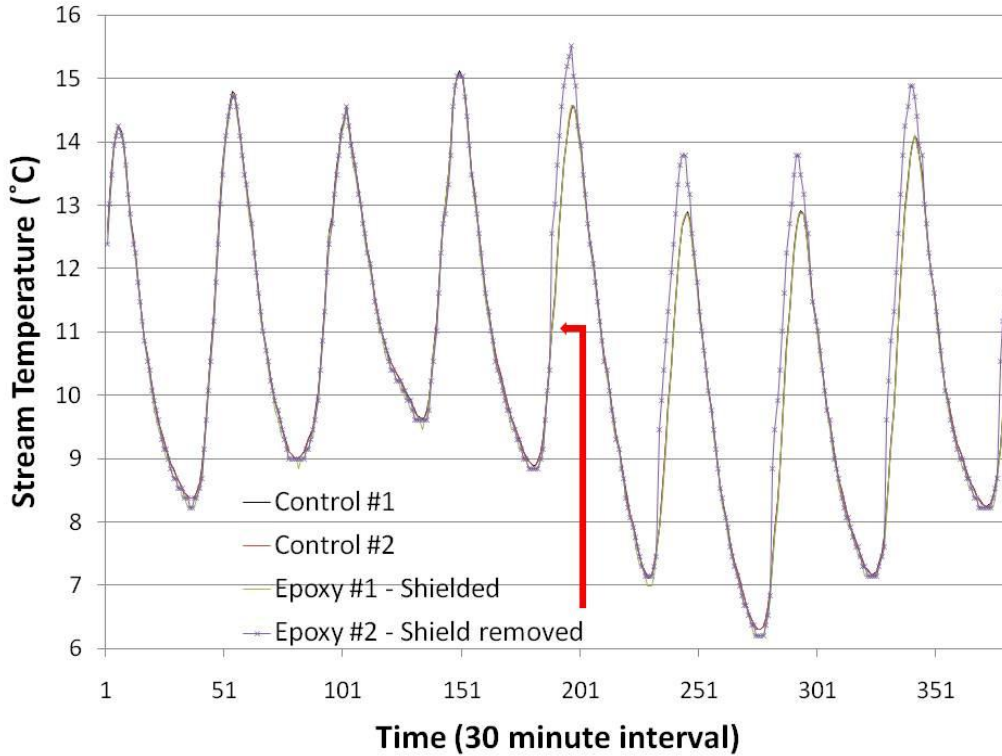


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Summary from field trials

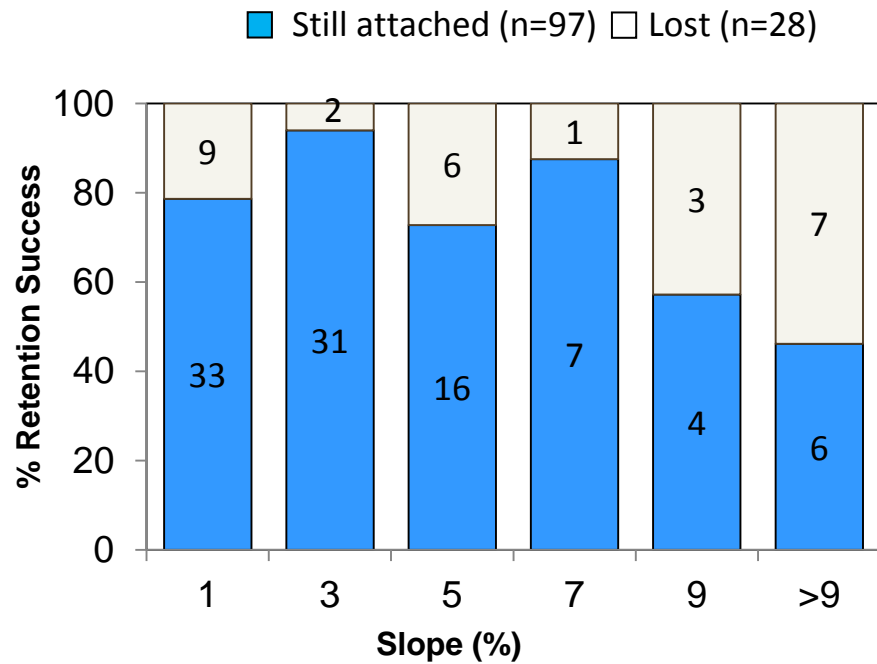
- Based on our experience, it takes approximately 20 minutes to install a temperature sensor once a suitable attachment surface is located. The Fox FX-764 epoxy has worked well in the range of stream temperatures tested (5°C – 20°C), but further tests should be conducted if the epoxy is to be used in warmer water temperatures.
- Field trials indicate that temperature readings are not biased by direct attachment to large boulders (possible heat conduction effect) and accurately reflect conditions in the surrounding stream based on comparisons to control sensor data (Graph 1, next page).
- Field trial results also suggest that sensors deployed with the Fox epoxy will easily withstand annual floods if attached to rocks large enough to remain immobile during floods and are in locations shielded from downstream bedload movement. A large-scale field assessment from the summer of 2010 to the summer of 2011 found that 78% (97 of 125 sites visited) of sensors were still collecting data one year later and had survived above average snowmelt floods in early 2011. Stream slope was inversely related to retention success, with 83% of sensors successfully retained where slopes were < 7% that are typical of most fish-bearing streams (Graph 2, next page).
- Additional details regarding the laboratory and field trials used to develop the epoxy method are in Isaak and Horan (2011). Please consult our stream temperature website for the latest version of this protocol as it is periodically updated. If you establish new full year temperature sites and are interested in having your sites shown on a dynamic GoogleMap as part of the rapidly growing monitoring network across North America, just drop us a note. The GoogleMap tool displays approximately 3,000 stream sites where full year temperatures are currently being monitoring and can be viewed at: http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml or just Google “Stream Temperature Boise” and we’ll turn up.

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Graph 1. Stream temperatures measured during an eight day July field trial assessment of solar shield effectiveness. Temperature traces overlap strongly during the first four days of the trial but temperature spikes are immediately apparent on day 5 after solar shields were removed from two sensors. Conclusion: solar shields are mandatory to avoid biased temperature measurements.

Graph 2. Retention success of temperature sensors deployed with underwater epoxy at 125 sites from summer 2010 until summer of 2011. Stream slopes ranged from 0.1% - 16%. The numbers in the columns represent the number of sites that were instrumented at that stream slope.



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Acknowledgements

We thank Art Butts of Idaho Fish and Game for his suggestion regarding the use of a screw-top PVC canister as a durable solar shield—a device which we affectionately refer to as Butts' Box.

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Visit **YouTube** for a quick demo:

<http://www.youtube.com/watch?v=vaYaycwfmxs&feature=youtu.be>



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Photos and Tips

Photo 1. Equipment needed to permanently install temperature sensors in streams using underwater epoxy includes: (a) FX-764 from Fox Industries, (b) underwater data shuttle (if data are to be retrieved *in situ*), (c) metal forestry tree tag, (d) temperature sensors (shown with neoprene flap for solar protection), (e) wire brush, (f) rubber gloves, and (g) plastic viewing box.



Photo 2. TidbiT thermograph with a neoprene flap attached as a solar radiation shield. Plastic cable ties are used to firmly attach the neoprene to the TidbiT. This solar shield is inexpensive, durable, and flexible to permit data downloads with the underwater shuttle. Periphyton quickly grows on the neoprene to camouflage the sensor.

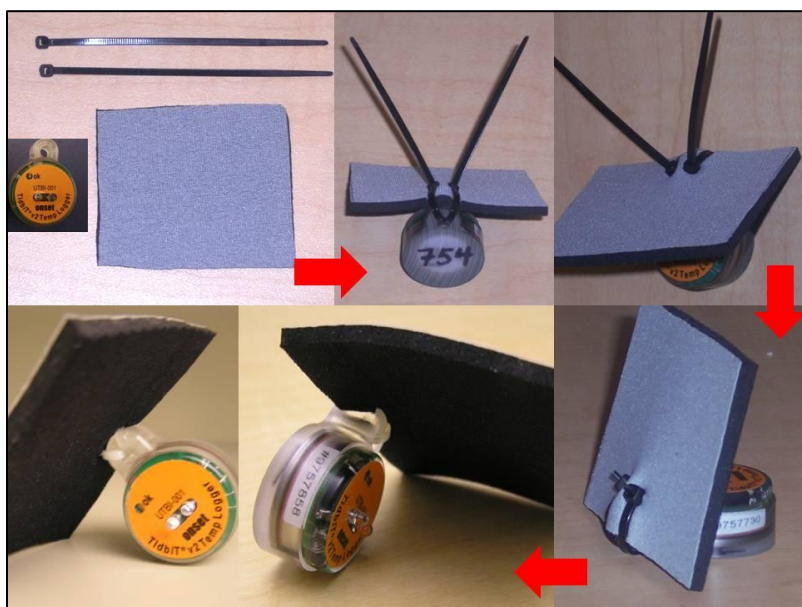


Photo 3. A small lead weight attached to the front of the solar shield causes the flap to hang in front of the sensor (providing the best possible protection against direct sunlight) and prevents the shield from being lifted by turbulent flows.



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Photo 4. Solar radiation shield comprised of a screw-top PVC canister. The temperature sensor is placed inside the chamber and buffered with a small piece of neoprene that is ziptied to the sensor. The entire unit is glued to a rock and the sensor may be removed for data retrieval or replacement. Holes should be drilled through the sides of the canister to make it neutrally buoyant and to facilitate water circulation. The canister must have a lip at the bottom that epoxy can be wrapped around as the epoxy will not hold the PVC to the rock without this step. Wrap the threads of the cap with Teflon tape.



The unassembled parts include a base, mid-section, and screw top (see Appendix A for part numbers).



Photo 5. Examples of boulders and bridges that provided good attachment sites because of their large size and flat downstream surfaces. Note the small substrate particles that are deposited behind several of the rocks. Arrows point to the sensor location, which is visible by the grey neoprene solar shield. The metal forestry tag and white spray paint are also visible above the sensors. Bridge pylons are good alternatives when large boulders are not available.

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Photo 6. Preparing the Fox epoxy for use involves extracting equal amounts of each component and mixing together for one minute until the color is uniform throughout. Fingers should be wetted before and during handling the epoxy to minimize messiness.



Photo 7. Fox epoxy applied to the back of a temperature sensor ready for deployment. Enough epoxy should be applied that it can cover the surface of the sensor to a depth of approximately 1/8 inch.



Photo 8. Temperature sensor attached to rock surface with the Fox epoxy in a laboratory setting. Once the epoxy fully sets, the sensors are cemented to the rock surface. Lower left panel demonstrates applying too much epoxy to attach the sensor, which would prohibit data retrieval with an underwater shuttle. Lower right panel shows a 5 pound rock held aloft by the sensor.

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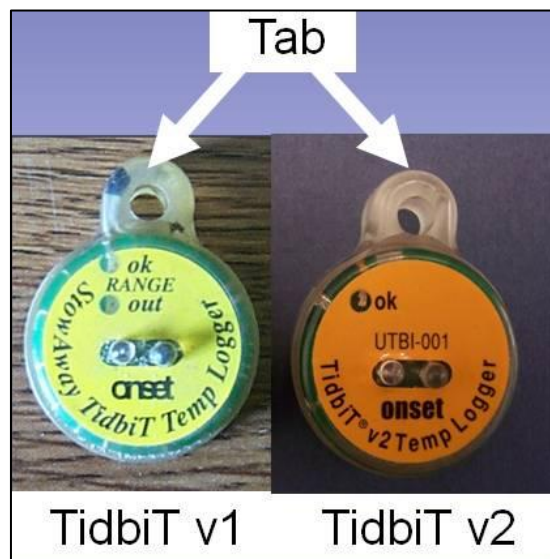


Photo 9. TidbiT temperature sensors manufactured by Onset Computer. The tab must point up when mounted on a rock surface to facilitate data retrieval with an underwater data shuttle. Underwater downloads are possible only with the newer, TidbiT v2 shown on the right. The TidbiT v1 may be used with the epoxy method providing it is enclosed in a PVC canister.



Photo 10. Examples of PVC canisters glued to rock surface. The left canister did not have epoxy applied up and over the lip on the base piece (in a lab test), but we did apply epoxy over the lip on the right canister. After a couple of weeks, the left canister was tapped with a hammer and it easily popped off the rock. We still cannot remove the canister on the right. We recommend that you use a canister with a lip and bring the epoxy up and over the lip during installation. In addition, we recommend gluing the bottom and mid-sections with PVC cement to ensure they stay connected.

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Photo 11. Inspecting a temperature sensor attached to a rock surface using a viewing box in the field. No gap should be apparent at the contact point between the epoxy and the rock surface.

a.



b.



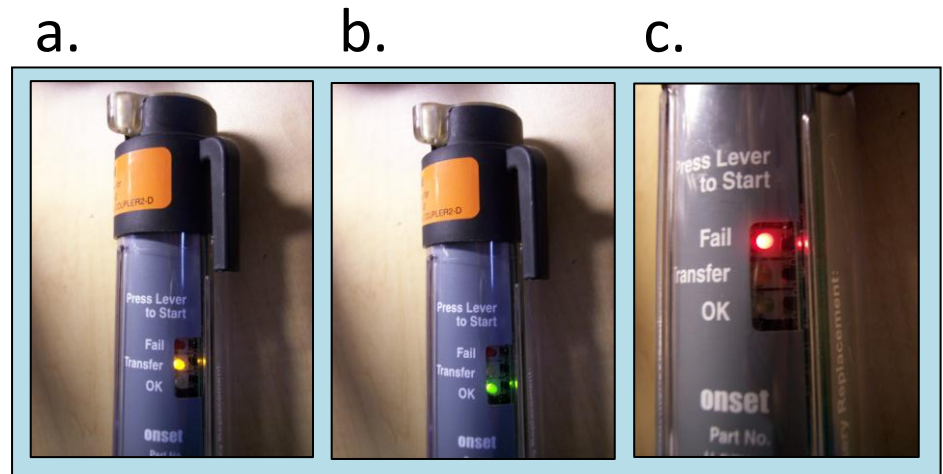
Photo 12. Temperature sensors glued to rocks in mountain streams - notice the rocks propped against the front of the sensors to hold them in place while the epoxy sets. (a) A sensor with a neoprene flap, and (b) a sensor in a canister. Smaller prop rocks than that shown in (a) are typically used because only a small amount of pressure is needed.

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Photo 13. Metal forestry tag attached to a rock using Fox epoxy to monument the location of a stream temperature sensor.

Photo 14. A TidbiT v2 temperature sensor that is attached to the Onset Waterproof data shuttle. During the successful transfer of data the (a) amber light blinks continuously and then turns to (b) green (for 15 minutes) after all data are downloaded. If data retrieval was unsuccessful the (c) red light blinks.



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Appendix A

Equipment needed to collect annual stream temperature using the epoxy protocol*

Product	Supplier	Web Address	Part number
Temperature sensor	Onset Computer Corporation	http://www.onsetcomp.com	UTBI-001 TidbiT v2
Underwater data shuttle	Onset Computer Corporation	http://www.onsetcomp.com	U-DTW-1 Waterproof Shuttle
Underwater epoxy	Fox Industries	http://www.foxind.com	FX-764 Splash Zone Epoxy
Jar: 60 ml (2 oz) Jar: 125 ml (4 oz) (optional, for epoxy)	Fisher Scientific	Fisher Scientific Or use jars from the Dollar Store	02891B 02891C
Underwater viewing box	Hoffman Manufacturing	http://www.hoffmanmfg.com	CONT79C
Metal forestry tags (numbered & blank)	Forestry Suppliers	http://www.forestry-suppliers.com	79142
PVC canister, 1-1/2" Screw top Mid-section Base	Hardware store		450-015HC 435-015HC 449-015HC
Lead weights, ¼ oz			
Neoprene, 3mm			
Rubber gloves			
Wire brush			
Zip ties, 4"			
Spray paint			
GPS			
Camera			
Datasheet			
Metal mirror			

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Appendix B

Sample datasheet for recording relevant information associated with the deployment of annual stream temperature sensors.

Page 1

Projection _____ Datum _____ Annual Stream Temperature Site Information Crew _____

	Drainage	Stream Name	Tidbit Serial#	GPS WayPt (initials & metal tag#)	Easting or Longitude	Northing or Latitude	Paint Color	Date In	Time In	Date Out	Time Out	Bank: Looking Downstream			Photo #'
												R	M	L	
1															
2															
3															
4															
5															
6															

Page 2

Projection _____ Datum _____ Annual Stream Temperature Site Information Crew _____

	Site Description
1	
2	
3	
4	
5	
6	



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Appendix C

Quick Start Guide for Installing Onset Sensor

1. Find large boulder (“charismatic megaboulder”) that:
 - a. Is protruding a foot or more above the water surface at low flows
 - b. Is wide enough to protect sensor from moving rocks/debris during floods
 - c. Has flat attachment site on downstream side and relatively deep water with flow
 - d. Has small substrate on downstream side and 8 in of space for shuttle attachment
2. Check sensor for indicator light. Record sensor serial number and metal forestry tag number.
3. Put on gloves and use wire brush to clean surface of attachment site (at least 2-3 in above stream bed). Place a few cobbles or suitably sized rocks near the sensor site to later lean against the attached sensor.
4. Moisten gloves and scoop out small amount (about quarter-size in diameter, 1/8 in thick) of white and black epoxy from each container, and mix together for at least 1 minute. Apply epoxy to back of sensor (or PVC canister) and metal forestry tag.
5. Gently push & slightly twist sensor (or PVC canister) onto attachment site.
6. Lean a rock against the face of sensor and check attachment site with plastic viewing box.
7. Attach forestry tag on boulder directly above sensor (above water line) and spray paint top of rock and around tag.
8. Mark the site as a waypoint on GPS and record UTMs on data sheet. Take several photos of site, and record photo #s on data sheet.

