STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Practical guidelines for monitoring movement of aquatic organisms at stream-road crossings

by Jason Dunham, Robert Hoffman, Iván Arismendi

Maintaining passage of aquatic organisms through modification or replacement of barriers (e.g., culverts) at stream-road crossings represents one of the Nation's largest investments in restoring aquatic ecosystems. Current federal guidelines specify stream simulation as the standard for passage restoration (Stream Simulation Working Group 2008). From a biological perspective the intent is to design crossings that allow for natural movements of native aquatic organisms, including species that depend on water for movement such as fish, amphibians, and aquatic invertebrates. The extent to which design standards, such as stream simulation, allow for natural movement of aquatic organisms remains a major question of interest.

The most direct way to evaluate aquatic organism passage is to monitor movements of individuals through crossings. Recent advances in tagging and telemetry (e.g., radio and acoustic telemetry, passive integrated transponders), as well as genetic methods of tracking individuals offer increasingly powerful approaches to track individual movement (e.g., Guy et al. 1996; Heyer et al. 1994;

Schwartz et al. 2007). These methods allow for individual identification and detailed analyses of individual movement, but can be expensive and technically challenging to implement.

In practice resources are usually more limited, and tracking of "batch" marked or tagged individuals may be a more feasible approach to evaluating individual movement. Examples include marks such as fin clips (fig. 1; Burford et al. 2009) and tags (e.g., external tags or injected dyes or polymers; Ficke and Myrick 2009; Guy et al. 1996). With this approach "batches" of generically marked or tagged individuals are released at a given location and subsequently recaptured or re-sighted to infer movement (fig. 1). Whereas methods of marking or tagging are often the initial focus of such studies, their design and implementation often have a greater influence on study outcomes. With this in mind, our objective here is to briefly review study designs that can be used with batch marking or tagging as a means of evaluating individual movement at crossings.

Study Designs

Stream-road crossings occur in a

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capture and marking
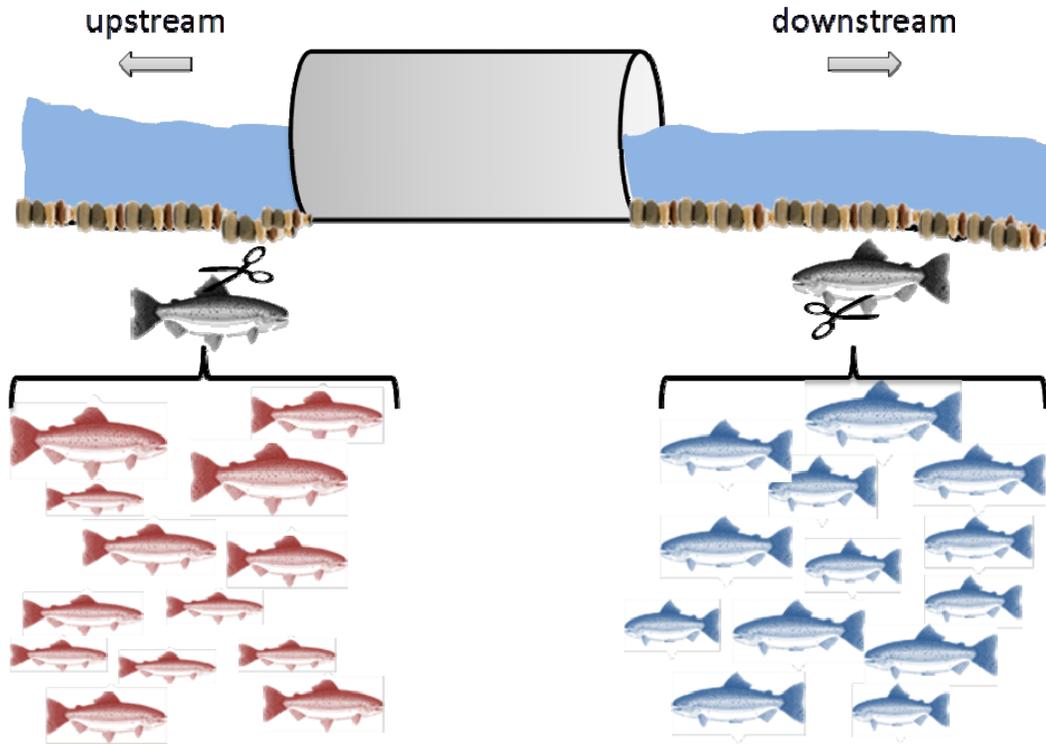
recapture

Figure 1. Illustration of mark and recapture of individual movement relative to a stream crossing. The example here is a culvert crossing and marking fish with fin clips (e.g. Burford et al. 2009).

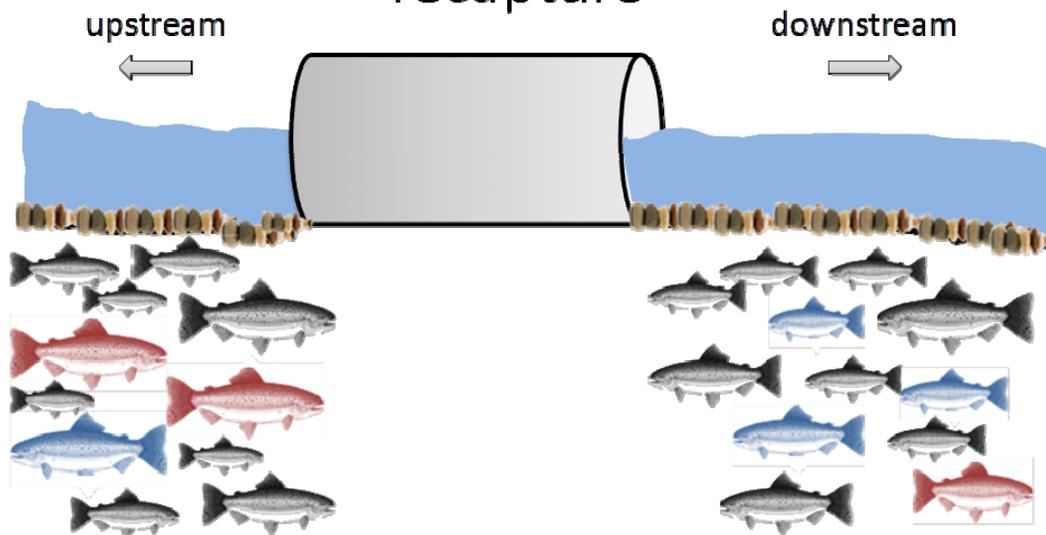variety of settings that can place important constraints on how movement can be evaluated, or in other words, study designs (fig. 2). This is a critical consideration because study designs limit the questions that can be addressed about movement over crossings. In all cases (fig. 2) it is possible to address the question of "Can individuals move over a crossing?" The question of "Is movement over a crossing similar to a natural stream channel?" can be addressed by designs involving a natural "reference" (fig. 2C, D).

The simplest question is "Can individuals move over a crossing." This question involves just a single site
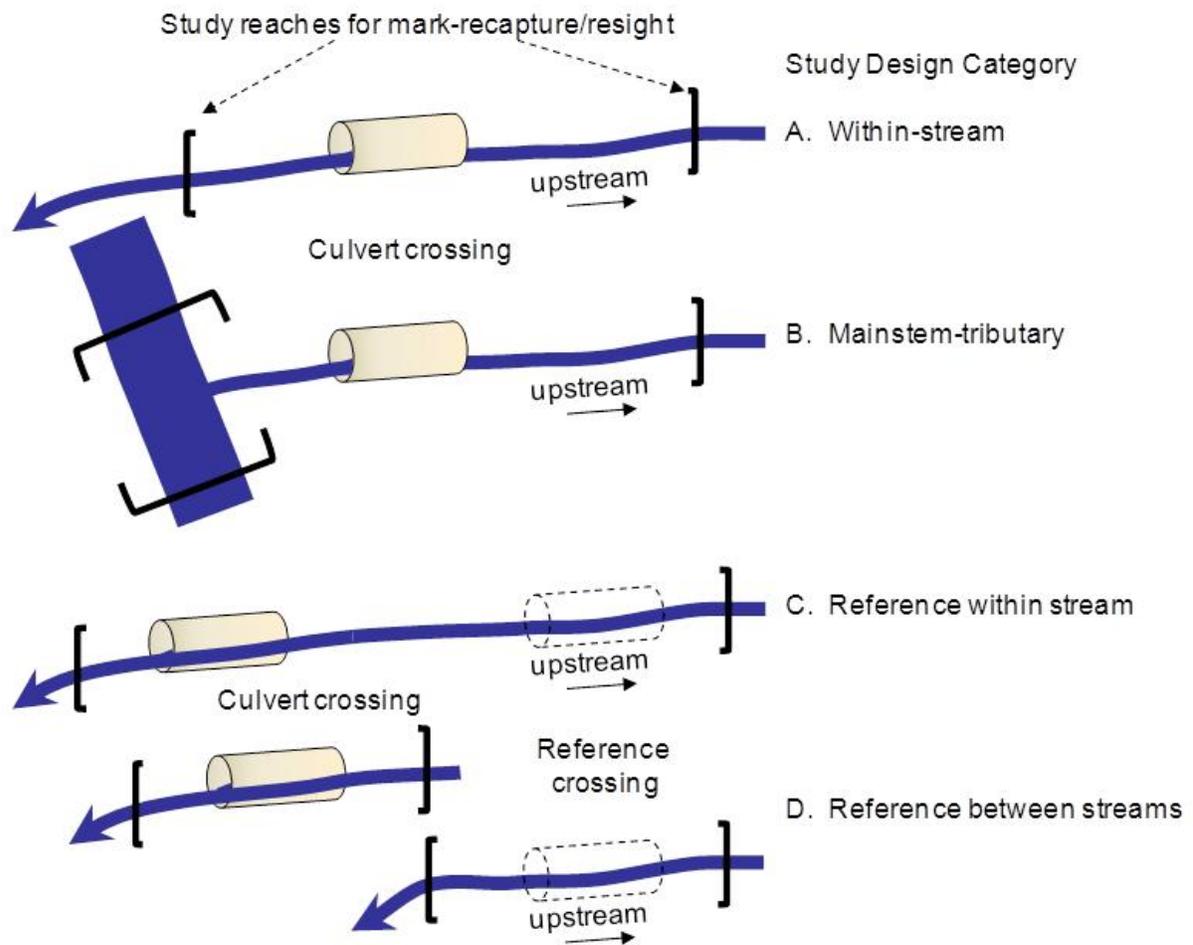
STREAM SYSTEMS TECHNOLOGY CENTER
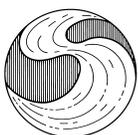
Figure 2. Study designs for mark-recapture or re-sighting studies of individual movement relative to culverts. All designs can be applied to address the simple question of individual movement over a crossing (e.g., a culvert or other structure), but a natural reference or "false culvert" (indicated by culvert with a dashed outline) is needed for comparative studies that evaluate the degree to which movement at a crossing is similar to a natural channel.

with individuals marked or tagged below a crossing (fig. 2A, B). Movement in an upstream direction is often the focus, due to the potential hydraulic constraints limiting upstream movement over the crossing (e.g., Burford et al. 2009). Individuals may also be tracked with respect to movement downstream over the crossing if there are questions regarding non-hydraulic influences on passage (e.g., behavioral avoidance).

A key assumption in this approach is that factors other than the crossing itself (e.g., hydraulic resistance to movement or behavioral avoidance) are not important for individual movement. For example, changes in habitat below or above a crossing can impact the propensity of individuals to move, even if the crossing is easily traversed. A simple example would be a stream that branches immediately above a crossing. Fish may avoid habitat upstream of such a

crossing because it is simply too small relative to habitat downstream. Changes in stream channel slope may similarly limit use upstream of crossings. A third example is the common case of smaller tributary streams entering larger mainstem rivers immediately downstream of a crossing (fig. 2B), or cases in which the crossing has affected channel morphology. Thus, it is important to ensure that habitats above and below crossings are similar with respect to the species' habitat requirements (fig. 2A). Similarity can be determined with respect to stream geomorphology (channel and valley type), hydrology (stream flow, flow regime), and biology (aquatic and riparian communities). In many cases, however, upstream and downstream reaches may differ substantially.

To address the question "Is movement over a crossing similar to a natural stream channel?," a comparison between a crossing and a natural "reference" is

needed (fig. 2C, D). In some cases, a reference site is referred to as a "false culvert" (e.g., Coffman 2005). The reference and culvert reaches must be similar enough that movement in the reference reach can reasonably be expected to represent the culvert reach if the road were absent. In practice it may be challenging to find exact matches between impact (e.g., culvert) and reference sites for comparison (e.g., flow, geomorphology, biology; see Roni et al. 2005 for a brief overview). Suitable reference locations may be found upstream or downstream of a given crossing (fig. 2C), or in a different stream if comparable conditions are present there (fig. 2D).

Study Implementation

Study implementation involves many steps such as identifying study locations and settings (see above); methods of marking or tagging; methods of recapture or re-sighting; sizes, ages, and life stages of species to evaluate; numbers of individuals to track; and timing, frequency, and duration of tracking. We collectively consider these factors in light of some major assumptions that apply to most studies of marked individuals: 1) lack of detection of movement through a culvert is not due to low expected probability of recapture; 2) movement is constrained by the crossing only; and 3) marking of individuals does not influence their behavior. Each of these factors is discussed below.

Assumption 1: Lack of detection of movement through a culvert is not due to low expected probability of recapture.

A key consideration in using a mark/tag-recapture or mark/tag and re-sight approach relates to expected sample sizes for recaptured or re-sighted individuals. This depends on several factors including 1) the number of individuals initially tagged or marked; 2) the degree to which tags or marks are retained or subsequently detected; and 3) survival and emigration of tagged or marked fish to the time of recapture or relocation.

Tag loss. Of the initial sample of marked individuals, some will lose their tags or marks or these will otherwise not be detectable after initial marking. For example, fin clips can regenerate within a few weeks, especially in the case of younger fish during periods of rapid growth. The rate of regeneration also depends on how large the fin clip is, and which fin is clipped. In salmon and trout, adipose fins are often clipped because they will not regenerate. Visible implant tags can be difficult to see if they are implanted in heavily pigmented tissues. They will also be lost or obscured as the individual grows. This reduces the number of individuals that will be possible to re-sight or recapture. External tags, such as disc, streamer, or "spaghetti" type tags (Guy et al. 1996) will also be lost over time.

Survival and emigration. Survival of most aquatic organisms is highly variable and typically depends on life stage. More specifically, juvenile mortality is high relative to adults. Thus, expected sample sizes for recaptures of juveniles would be less, due to increased mortality between marking or tagging and recapture or re-sighting. Movement of individuals outside of sampling locations will also reduce the number of expected recaptures. Many species can move extensively, and in most cases it is impossible to sample all potential locations that tagged or marked individuals could have moved to within a system (see Albanese et al. 2003).

Maximizing expected recaptures. Given that several factors may conspire to reduce the number of expected recaptures, an obvious solution is to maximize the number of individuals that are tagged or marked and/or recovered. Numbers of fish captured and tagged or marked can be increased by sampling across larger areas. However, the expected increase in numbers of captured individuals is partially offset by the fact that more individuals will be captured further away from the crossing. Individuals located farther away from a crossing may be less likely to move distances needed to reach the crossing, let alone pass through it.

Where appropriate, it may be possible to release tagged or marked individuals closer to crossings to increase numbers for evaluating passage and increase the probability of an observed crossing. Releasing individuals from above the crossing downstream of it may provide additional motivation to pass through the crossing, as many species show fine-scale homing behavior (i.e., attempting to return to their original upstream location in this case). This technique is commonly applied in other settings (Knowlton and Graham 2010). To our knowledge, this technique has not been applied in the context of aquatic organism passage, but merits consideration in cases where numbers of individuals are limited, or there is reason to suspect that individuals may not otherwise be motivated to move.

Another way to increase expected recaptures is to increase the monitoring effort. Obviously monitoring
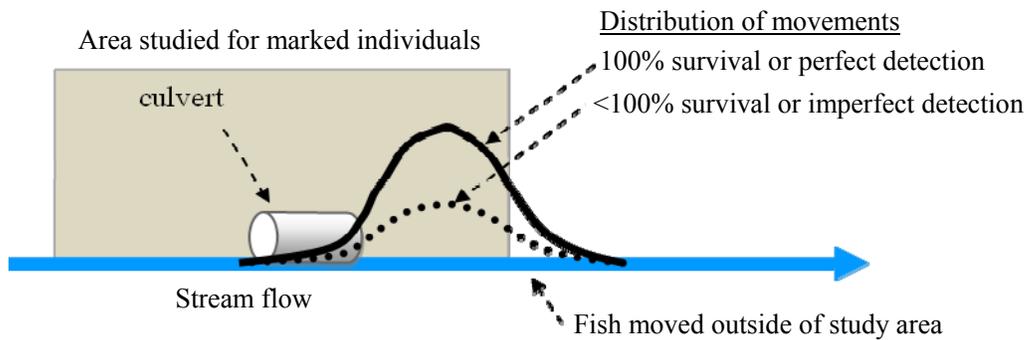
Figure 3. A hypothetical study area (downstream batch-marking or tagging only) for mark and recapture or re-sighting of individuals. The bell curve depicts the distribution of movements of recaptured individuals. Some of these individuals may leave the sampled area and thus be lost to the potential pool of recaptures ("Fish moved outside of study area"). Others will be lost due to undetectable marks, death (or emigration) before the recapture event, or imperfect probability of recapture (present, but not captured). The top bell curve (solid line) depicts available marked fish (for recapture) assuming no death (or emigration) and perfect detection. The lower bell curve (dotted line) depicts impacts of mortality and imperfect detection. Note in the latter case that fish entering or passing through the culvert may not be detected, even though there is a low level of passage. This is due to a low expected number of marked individuals recaptured (see text for how to calculate this). Note this is a simple hypothetical example for illustrative purposes and may not represent actual patterns of fish movement (e.g., "long-tailed" or leptokurtotic distributions commonly associated with movement distances; Rodríguez 2002).
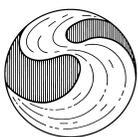
movements more frequently can be helpful in this regard, provided that such efforts do not adversely influence movement. Such efforts may also be more likely to detect possibility of circuit movements: cases where an individual on either side of a crossing could move across it and back to its original location. Capture or recapture methods with higher efficiency also merit consideration. For example, night-time snorkeling or electrofishing can be highly effective, if it can be conducted safely (Thurow et al. 2006; Saunders et al. in press).

Estimating expected numbers of recaptured or re-sighted individuals. Based on a relatively simple probabilistic framework (see also Norman et al. 2009; fig. 3) it is possible to approximately estimate the expected number of recaptured or re-sighted individuals. To calculate expected numbers of recaptured or re-sighted individuals, multiply the initial number of tagged or marked individuals by the expected tag or mark loss rate (a fraction between 0 and 1). Multiply this number by the expected survival (0-1), multiply this number by the expected probability of staying within the study area (0-1), and this number by the expected probability of recapture or re-sighting (0-1). The resulting number is the expected number of recaptured or re-sighted individuals. This is a useful (and often sobering) exercise for thinking about appropriate numbers of individuals to mark to ensure an adequate sample size

of recaptures. Even if estimates of these quantities are unknown, it can be useful to consider different hypothetical scenarios (e.g., hypothetical values of the parameters in a spreadsheet) for an evaluation. An additional multiplier can be added to explore the expected number of recaptured or re-sighted individuals that move over a crossing (probability of crossing ranging between 0-1).

A few examples illustrate a range of possibilities. For example, if we assume that we initially tag a sample of 100 fish and that the fraction of individuals retaining visible marks is 0.9, survival is 0.9, fraction of individuals staying in the study reach is 0.9, and probability of recapture is 0.9, then we expect to recapture about 66 individuals (=100*0.9*0.9*0.9*0.9). This is a *very* optimistic scenario. If we sample with the same probabilities, but reduce the probability of recapture to 0.3 (a bit more realistic) the expected number of recaptures is 22. If more fish move (0.7 stayed in the study reach) and recapture probability is lower (0.3), then even fewer recaptures are expected – about 7 fish. This leaves little chance for detecting individuals that may move over a crossing.

Reported estimates of these parameters vary widely in the literature, as may be expected given the wide range of conditions that are possible. For example, capture efficiencies for trout have been reported to vary between approximately 10-60% using single-

pass electrofishing (Peterson et al. 2004; Rosenberger and Dunham 2005), and observation efficiencies have been reported to be approximately 10-30% for daytime snorkeling (Thurow et al. 2006). These estimates can be used to approximate recapture or re-sighting probabilities for calculations outlined above (e.g., values ranging between 0.10 and 0.60). Estimates of survival are difficult to obtain, as survival is usually estimated as "apparent" survival, which combines probabilities of survival and emigration, or in some cases probabilities of survival, emigration, and tag loss (Norman et al. 2009). Similarly, it can be very difficult to estimate probabilities of emigration, but a range of possibilities based on biological characteristics of different life stages, seasonal influences, or other factors may be used to provide rough estimates useful for study planning (Rodríguez 2002).

Assumption 2: Movement is constrained by the crossing only.

As mentioned above, abrupt spatial changes in stream size (e.g., tributary branching immediately upstream of a crossing, loss of surface flow), steep gradients, waterfalls, or other physical impediments influencing an individual's ability to move may be important. Over time, changes in seasonal stream flows, temperatures, photoperiod, or other factors may also influence activity and movement.

Movement may be physically possible, but biological factors may also pose constraints. The presence of predators (e.g., larger fish) in a culvert outflow pool may cause avoidance of such habitats by some individuals. Species with limited home ranges or other behavioral constraints on movement may similarly be constrained. The propensity for many species to move varies seasonally, and is often timed to coincide with changes in physical conditions within streams. Upstream or downstream directed spawning or seasonal refuge migrations are common. Commonly observed seasonal patterns of downstream emigration by migratory species may also limit upstream movement through crossings.

In some cases movement over the crossing may be greater than expected, based on characteristics of the crossing alone. Some species may move overland, including most crayfish and amphibians. Efforts to mark and recapture individuals in terrestrial habitats might be necessary if the species studied is semi-aquatic. In cases where factors other than a crossing may constrain movement, it might be prudent to remove the constraint (if possible) or consider a different location for study that lacks this confounding influence.

Assumption 3: Marking of individuals does not influence their behavior.

This is a fundamental assumption of all tag/mark and recapture or re-sighting studies. Marking or tagging should not influence movement behavior in particular. For example, overzealous fin-clipping or handling of fishes may reduce their ability to move after marking.

Data Analysis

The simplest way to evaluate the results of a study of individual movement is to summarize the proportion of originally tagged or marked individuals moving over a crossing (e.g., single crossing, fig. 2A, B) or to compare proportions moving over a crossing relative to a reference (fig. 2C, D). Proportions estimated from the results of a single recapture or resighting event with accompanying confidence bounds can be easily estimated by hand (Ramsey and Schafer 2002). Paired comparisons of estimated proportions of individuals crossing in upstream versus downstream directions or individuals crossing relative to a reference (fig. 2C, D) are possible. These rather simple analyses assume that movement over the crossing is the primary factor influencing these proportions, and that they are not substantially confounded by other influences such as differences in habitat, unequal survival or emigration, or unequal detectability. In essence, such comparisons are qualified by assuming "all else is equal." More complex models can be applied when such is not the case and involve binomial (logistic regression) or count-based (Poisson or negative binomial regression) approaches that require more advanced analytical skills (Ramsey and Schafer 2002; see also MacKenzie et al. 2005).

Concluding Thoughts

Although commonly used, tracking movement of batch-marked individuals can suffer substantial bias. Whereas there are excellent case studies reporting success with this approach (e.g., Burford et al. 2009; Ficke and Myrick 2009; Bouska and Paukert 2010), for reasons described here failure to detect passage by tracking movements of individuals is not definitive evidence of passage impairment. Failure to detect movement in many situations is a real possibility and likely in many situations encountered in practice. In

this regard, it is worth noting that such instances are much less likely to be reported in the scientific literature (Scargle 2000). Therefore, the existence of successful applications in the scientific literature does not guarantee similar success in practice!

Consideration of the factors discussed herein can help to minimize, but not entirely eliminate the various sources of bias in tracking movement of batch marked or tagged individuals. For a given situation, analysis of these biases may shed some serious doubts on the feasibility of tracking batch marked or tagged individuals as a means of evaluating the effectiveness of aquatic organism passage. Alternatively, it may provide reassuring evidence for proceeding with a reasonable expectation of successful outcomes. If a preliminary analysis suggests that this approach is not feasible, other potentially feasible alternatives exist (see online presentations at http://www.stream.fs.fed. us/fishxing/PEPaop.html). These approaches may be more expensive or technically challenging, but the overall costs may be lower than the risks of engaging in a study that may produce little or no usable results.

Acknowledgements

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John Potyondy, STREAM Program Manager Retires

John Potyondy, Program Manager for the National Stream Systems Technology Center, has retired after almost 40 years of federal service; 3 years with the Peace Corps and 36 plus years with the U.S. Forest Service. John began his career as a hydrologist on the Marcell Experimental Forest in Minnesota. He subsequently served as a hydrologist on the Wasatch-Cache National Forest, an assistant regional hydrologist in the Intermountain Region, and a forest hydrologist on the Boise National Forest. John joined the newly formed "STREAM TEAM" in 1992 and became the STREAM program manager in 2004.

"It has been a real privilege to work with dedicated people and supervisors for whom I have infinite respect, admiration, and affection," said John. "When I started, it truly was a Forest Service family with a common, well understood mission and a desire to protect and preserve the land entrusted to us. I have also been fortunate enough to see many of the National Forests across the United States and have worked with many of you to protect soil and water resources and keep water in our stream channels for future generations ; a common mission and goal that we hydrologists share."