

Measuring watershed health: training conservation planners how to use biophysical tools for monitoring streams in neo-tropical ecosystems

Watersheds are the natural building blocks of conservation areas. They are the sources of the clean fresh water that is the life's blood of all living things, from the largest mammals to the smallest microorganisms. And because they are also the drainage systems for all activities on the land, their streams and rivers are sensitive and accurate barometers of the ecosystem's health. Yet, despite the critical role that water plays in the life and biodiversity of conserved areas, little is known about the condition of the streams and rivers that convey it to the Andes-Amazon region. The absence of such knowledge has meant that the quality and quantity of fresh water have typically not been included in conservation plans, with the result that landowners, conservation workers, and policy makers have lacked an invaluable tool to help them establish conservation priorities, measure the success of conservation efforts, and calculate the true value of conserved land.

The goal of the Stroud Center's project was to demonstrate the feasibility and value of using information on water quality, water monitoring, and stream health to support and strengthen the Moore Foundation's Andes-Amazon initiative directly – and other Moore initiatives such as the Wild Salmon Ecosystems and the Conservation International initiatives indirectly. Because the Andes-Amazon is the world's largest river basin and the source of 20% of Earth's fresh water, because the area continues to support the world's most abundant biodiversity, all of which is dependent on fresh water, and because the region is under growing assault from a variety of sources, we believe that understanding the condition of its water and preserving the sources of that water, as both habitat and critical resource, must be the foundation of an effective conservation strategy in the Andes-Amazon. Moreover, the fundamental element in protecting clean fresh water is to protect the rain forest, particularly in the headwaters areas and along the stream corridors – for it is from the seemingly insignificant small streams that more than 90% of the fresh water actually comes; and the key to protecting the forest and its inhabitants, large and small, is to safeguard its sources of clean water. Finally, the streams and rivers themselves contain an astounding – and largely unrecognized – level of diversity of plants and animals. Most of them are barely visible to the naked eye, but they underpin all life in the region.

Our plan was simple. First, Stroud Center scientists would carry out an intense field and laboratory effort to produce a credible set of data that described the quality of streams and rivers – both pristine and polluted – in the Andes-Amazon region. Stroud Center educators would translate the technical data the scientists had collected into information and programs that would enable people in the region to understand the issues affecting their water, acquire the tools to protect the sources of that water, and grasp the vital connection between protecting the water and preserving the watersheds from which it comes.

The major premise of the project is that streams in preserved watersheds of the Andes-Amazon region can and should play a dual role in conservation strategies: they are both (1) the habitat for a largely uncharted reservoir of aquatic biodiversity and (2) a yardstick – the natural equivalent of the canary in the coal mine – that can provide:

- a measure of the important ecosystem services (e.g., filtration, treatment, and delivery of fresh water for humans and wildlife) that are being conserved and the value of those services for the health and sustainability of the region and the biosphere;
- a benchmark for assessing on-going efforts to conserve pristine watersheds and restore degraded ones;
- a time stamp for existing conditions that enables policy makers and others to measure the impacts of local development, regional transport of pollutants, and global climate change; and
- the living classrooms for hands-on programs that educate teachers, decision makers, and the general public about the critical need to establish and maintain core preserved areas.

Guided by the above, scientists, technicians, and educators from the Stroud Center, along with collaborators from Florida A&M University and Peru, made several trips to the Andes-Amazon region in 2006 in support of the Moore Foundation's conservation efforts. The teams had two main goals: (1) to create a baseline of scientific data on water quality, stream biodiversity, and stream health that will serve as the foundation for understanding and sustaining on-going conservation efforts in the region; and (2) to craft, test, and implement accessible, easy-to-use, and inexpensive education programs for the people of the region.

It is critical to establish a baseline against which to measure the impact of future changes in the region. Nowhere is this more true than in the frontier areas, such as that around Puerto Maldonado which is undergoing a momentous transformation as a result of ongoing gold mining operations and, perhaps even more importantly, the anticipated construction of a paved highway and bridge across the Madre de Dios. This baseline of freshwater conditions, habitat, and living organisms becomes even more important in the face of global climate change: aquatic organisms are more sensitive to temperature change than terrestrial communities because they are adapted to environments with much less variation in temperature. Hence, these "aquatic canaries" are likely to respond more quickly and with more dire results to small and sudden changes in temperature.

We also believe that it is imperative to engage the local residents in the efforts to understand the complex issues facing their region and its water and to help them become active stewards of their resources. In the course of our work we were often told that conservation is viewed as something "outsiders" are trying to impose on the local communities and that, while the stated benefits of conservation efforts are global in scope, the costs are disproportionately borne by local residents, many of whom are very poor and desperate for economic development. The cash and jobs that are currently generated by gold mining and are anticipated from the construction of the highway and the development of the surrounding countryside are perceived as having more immediate value than the preservation of the rainforest. It is essential, then, to demonstrate the real and quantifiable benefits that will come with the protection of the forest and the sources of fresh water. And those benefits, which include direct economic impacts such as ecotourism, improved public health, and significantly reduced water treatment costs, are substantial.

Accompanied by as many as 39 large black bags of scientific research equipment, the group hewed to a precise but hectic schedule (e.g., see Table 2.1 in Appendix 2) to accomplish its goals. Operating out of five eco-tourist/research stations on the Madre de Dios and Tambopata

ivers, the scientists and educators worked in the field, laboratory, and classroom to accomplish three major outputs:

1. Create and offer training workshops for monitoring biophysical properties of streams and rivers in neo-tropical regions.
2. Test and deploy protocols for measuring and monitoring health in neo-tropical streams.
3. Disseminate training workshop and monitoring research information.

The report that follows describes what the Stroud Center team did with regard to each of those outputs, why we did it, and what we found.

Output 1. Create and offer training workshops for monitoring biophysical properties of streams and rivers in neo-tropical regions.

What we did

During the two-week trip to the Peru in August, Stroud Center scientists and educators worked side by side to get a clear understanding of the local stream conditions and community issues and to pilot test a workshop for students and teachers from Puerto Maldonado, the capital and largest town of Madre de Dios. That workshop served as a prototype for two series of daylong workshops to be given later in the year in Madre de Dios and the Osa Peninsula of Costa Rica.

In October two educators and two scientists from the Stroud Center presented four separate, full-day workshops on water quality monitoring and the ecology of streams and rivers in the Andes-Amazon region. The workshops took place at the ACEER-Tambopata at Inkaterra (ATI) station just downstream from Puerto Maldonado on the Madre de Dios River (Figure 1). In December



Figure 1. Hands-on stream insect sorting and identification by participants of a water-quality monitoring workshop near Puerto Maldonado, Peru.

the group traveled to Costa Rica to give a similar series of workshops at the Fundacion Neotropica on the Osa Peninsula (Figure 2). Presented in Spanish and offered free of charge, the workshops bolstered the conservation efforts of core preserved areas in the neo-tropics, discussed the latest scientific and educational knowledge on issues affecting fresh water, offered practical and affordable methods for monitoring streams and rivers, taught stewardship practices that the participants can both use themselves and transmit to others, and encouraged



Figure 2. Learning to identify Costa Rican stream insects at the Fundacion Neotropica on the Osa Peninsula

appropriate conservation policies in the region – particularly the importance of maintaining forest cover. In addition to enhanced knowledge and new communication techniques, the workshop participants received resources, in the form of handouts, CDs, and web links, to help them share their newly acquired information in their communities.

Each workshop began with a lecture on the local and global importance of clean fresh water, the many roles clean

water plays in the participants’ personal lives and local economies, a basic understanding of the ecology of streams and rivers, and usable ways to determine the health of the water in their communities. The opening lecture set the stage for the rest of the day by framing the issues, providing simple but essential statistical and general information about water resources, explaining the relationship of land use to stream health and the impact of human activities on water quality (e.g., Figure 3), and discussing the critical role that streams flowing through conserved areas play in the region. The workshops were enriched by the findings generated by the Stroud Center’s current study, as well as the

knowledge the Center has gained from two decades of working in neo-tropical streams in Central and South America.

Workshop participants (see Tables 1.3 and 1.4, Appendix 1) then walked two kilometers to a nearby stream where they waded into the water to perform actual measurements of water quality and to collect macroinvertebrate animals – aquatic insects, snails, crabs, and worms – that provide a biological measure of stream health (Figure 4). The group learned how to make basic

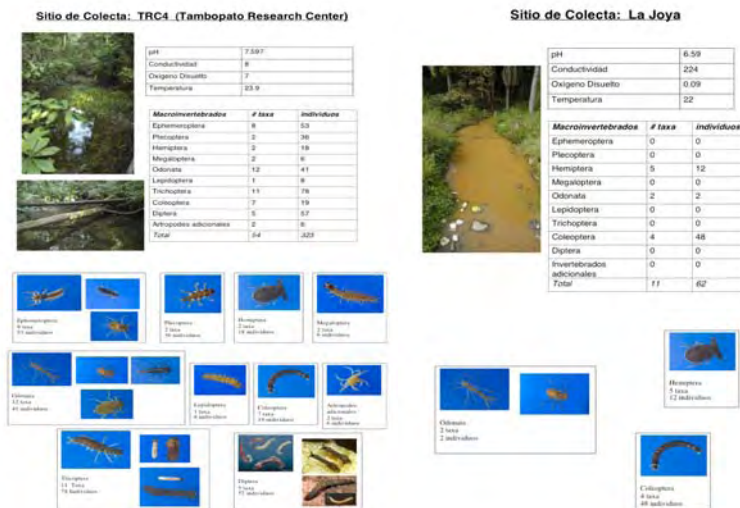


Figure 3. An example of the stream insects that can be found in a ‘healthy’ stream (on the left) compared to those found in an ‘unhealthy’ stream (on the right). Both streams are located in the Madre de Dios River basin, Peru.



Figure 4. Collecting stream insects for assessing stream health in Peru and Costa Rica

measurements of water flow and chemistry and to collect and identify aquatic organisms. They then returned to the station for lunch, during which an entomologist described the role the stream animals play as indicators of water quality. After lunch, the participants spent a couple of hours in the laboratory, sorting and identifying the animals they had collected that morning. They learned how to assess the health of the stream and watershed by analyzing the abundance and types of species and higher taxa they had found (Figure 5), how to use simple and effective tools to monitor their streams and

and how to compare the clean stream at ATI with others in the region that the Stroud team was studying. The day ended with a boat trip to Inkaterra’s Reserva Amazonica and a visit to its famed canopy walk, which was accompanied by a discussion of the critical relationship between the rainforest and the health of the sources of fresh water.



Figure 5. Making the connection between healthy streams (based on the macroinvertebrates found) and healthy watersheds.

As noted above, the December workshops in Costa Rica took place at the Fundacion Neotropica in the town of Rincon on the Osa Peninsula. Rincon lies in the heart of a conservation corridor currently being created between Corcovado and Piedras Blancas national parks, in large part by a grant from the Moore Foundation to The Nature Conservancy. The sparsely populated area is under intense pressure from a project to complete construction (pave/new bridges) of the coastal highway that connects Costa Rica’s capital of San Jose with

Panama via the Osa peninsula. Using a format similar to that offered in Peru, the workshops in Costa Rica blended scientific data from Peru and Costa Rica to frame the issues and to provide the appropriate context and perspective for the participants. The workshops were well attended, received excellent reviews, and provided additional feedback on how best to use water quality monitoring data to support and promote conservation in neo-tropical watersheds.

Why we did it

After a number of discussions with people in the region on content, logistics, and potential participants, the Stroud Center's scientific and education staffs decided that the best way to reach the most diverse and significant audiences and to maximize the impact of the work we were doing was to give a series of daylong workshops geared specifically to the following participants: (a) local public- and private-sector decision makers; (b) teachers; (c) conservation planners, non-governmental organization staff members, and university faculty; and (d) ecotourism guides. This focus enabled us to target our educational efforts at groups that could both use the information in their own work and influence a range of audiences that would ensure a broad dissemination of the issues, information, knowledge, and monitoring techniques. It also enabled us to engage in discussions with local leaders and workers who are currently in positions to make decisions about the use and protection of water resources and with teachers whose students will become the stewards of the future.

Consequently, each workshop was designed not only to teach the participants about freshwater issues, monitoring techniques, and stewardship practices but also to show them how to pass on to others the knowledge they acquired. To do that, we built into the workshops: exercises for teachers to use with their students; information that ecotourism guides can add to their inventory of activities for their clients; ideas that decision makers can introduce into the local political and corporate processes; and practices that conservation planners and NGO staff members can incorporate into policies and programs.

Because conservation efforts are often viewed as something outsiders are seeking to impose on the region, it is imperative to engage the local people in the efforts to understand the complex issues and to become active stewards of their resources. It is much easier for the area's residents to understand the immediate benefits of the cash and jobs being generated by gold mining and anticipated from the construction of the highway and the accompanying development of the surrounding countryside, than the long-term value from the preservation of the rainforest. It is essential, then, to demonstrate the real and quantifiable benefits that will come with the protection of the forest and the sources of fresh water.

What we found

The workshops were well attended and enthusiastically received. We found among the participants a clear and growing recognition of many of the issues that currently face the region and its fresh water – and, even more importantly, of how vulnerable the area is to the enormous changes that are on the way. The most conspicuous current issue is the widespread gold mining in the rivers – a practice that is exposing the entire food chain, from the smallest aquatic organisms to humans, to increasing levels of mercury. But the issue that may ultimately prove

the most cataclysmic is the paving of the Acre-Masuko Highway (connecting Acre, Brazil with Masuko, Peru and ultimately beyond to Cusco), which includes the construction of a bridge across the Madre de Dios River at Puerto Maldonado. While the paved road and bridge, which are expected to be completed within two years, are touted as a commercial transport system that will connect the hinterlands of Brazil and Peru to coastal markets, their most important impact will be to open vast tracts of land to agricultural and other development. In fact, it is estimated that 120,000 hectares will be transformed from rainforest to agriculture, which represents a tenfold increase in the area currently under cultivation. Thus, the watersheds around Puerto Maldonado and along both sides of the proposed highway are clearly watersheds in major transition; and land speculators are actively buying properties in anticipation of the enormous population growth and development already under way in the region. It is imperative that baseline technical information on land use and water quality be acquired in these watersheds before the development occurs so that preservation strategies and development impacts can be accurately measured in the future.

Our workshops also focused attention on the value of the region's streams and rivers – particularly the smaller streams that are the primary sources of water in the overall water system – and the role they play in ensuring clean safe water for drinking, sanitation, agriculture, and industry (including tourism). Drawing parallels to the Stroud Center's six-year study of New York City's drinking water supply system, which covers over 5,000 square kilometers and extends more than 200 kilometers from the center of the city, our presentation demonstrated the critical need to establish a baseline of current water conditions against which to measure future changes and to put good stewardship practices in place before the changes occur.

We found a remarkable thirst for information among the local participants – and a particular interest in the quantifiable economic and health benefits that come with the protection of water resources and the places that produce them. Participants, who ranged from outdoor guides to classroom teachers, from nurses to the president of the country's foremost eco-tourist company, were anxious to learn about threats facing their water sources, methods they can use to monitor the health of their streams and rivers, practices they can afford and implement to promote good stewardship of their resources, and ways to communicate what they have learned to others. Perhaps the most consistent message that came through in both verbal and written commentary on the workshops was “we want more” – more information, more time to learn, more and better tools to make a difference, more workshops in the future for more people to attend. A corresponding message was “we want it now” . . . because, with the rate of change in the region, time is of the essence.

A total of 153 people attended the eight workshops – 31 eco-tourist guides, 34 public and private sector managers, 42 teachers, and 46 conservation workers – with 80 participants in Peru in October and 73 in Costa Rica in December. We provided evaluation forms (see Table 1.5 in Appendix 1), in which we asked the participants to rate the workshops in four categories, using a numerical score of 1 (lowest) to 5 (highest). The average cumulative scores for the 8 workshops ranged from 4.6 to 4.9 (see Table 1.5 in Appendix 1). We also asked for general comments and have attached a compendium of those to this report (see Table 1.6 in Appendix 1).

Output 2. Test and deploy protocols for measuring and monitoring health in neo-tropical streams

What we did

The Stroud Center scientific staff, joined by other collaborators, local technicians, and guides, set up a series of measuring and monitoring stations across the Madre de Dios region. The overall goals were to: (1) measure a suite of physical, chemical, and biological parameters that will enable scientists, conservation workers, and the general public to understand the issues affecting their fresh water and gauge the health of their streams; (2) provide a quick, simple, and effective assessment of the impact of humans on water quality and stream conditions in the region; (3) create a baseline of water conditions against which to measure future changes – from factors ranging from local development to global climate change – in the region’s streams and rivers; and (4) establish a set of protocols that will allow people in the region to measure, monitor, and manage the health of their streams.

The Stroud team sampled 31 stream and river sites (Figure 2.1 in Appendix 2) that ranged from pristine – which are primarily in core conservation areas – to those that have been severely polluted by human activities (Table 4 and Appendix 2). The methodology and parameters selected for these studies (see appendices 3-8) were based on those developed by Stroud scientists over the course of their six-year assessment of water quality and stream health for all the streams that provide New York City its drinking water (for results of that study, see <http://www.stroudcenter.org/research/nyproject/JNABSPublications.htm>)

Why we did it

The water resources of the Andes-Amazon have been little explored – and, in particular, little is known about the quality of water and the integrity of the stream and river ecosystems that supply water to humans and wildlife throughout the region. This scientific deficiency is critical because clean fresh water has become, in the words of E.O. Wilson, the “deciding element on the planet earth.” If watersheds are the natural geographic bodies for land conservation efforts in the Andes-Amazon region, then streams and rivers provide the lifeblood for those efforts because: (1) all life in our watersheds needs a daily source of clean fresh water to survive and reproduce; and (2) every aspect of human existence – from agriculture to commerce to health – requires large amounts of fresh water. Yet, the quality and quantity of fresh water has typically not been included in most conservation plans, especially in the neo-tropics. Indeed, the supply of clean fresh water is rarely part of the equation used to calculate the short- and long-term values of conserved land; and water quality and stream monitoring are rarely part of the system used to establish conservation priorities or to measure the success of conservation efforts. As a result, the local population lacks the capacity to understand and monitor the condition of their streams and rivers and the quality of their fresh water.

Thus, the project’s intense scientific field effort was intended to provide the foundation on which to build a series of education programs which would distill and translate the technical data into understandable and meaningful information to enable those who live and work in the Andes-

Amazon to assess and monitor their sources of fresh water and to connect that knowledge to the overall conservation effort. Specifically, we have sought to teach those in the region:

- how the health of a local stream affects the physical and economic well being of those who depend on its water;
- how human activities on the land affect the quality and quantity of the water in the streams and rivers;
- how conservation areas protect the sources of clean fresh water;
- how people can manage and monitor the water sources in their communities;
- how the water quality information can be used to determine conservation priorities and measure their success; and
- why they should press local decision makers to implement policies to safeguard the region's clean fresh water.

What we found

A total of 31 stream and river sites were studied (Fig. 2.1, Appendix 2) across six scientific disciplines (Table 2.2; Appendix 2): Biogeochemistry (Appendix 3), Molecular Tracers of Contamination (Appendix 4), Microbial Diversity/Ecology (Appendix 5), Macroinvertebrate Diversity/Ecology (Appendix 6), Nutrient Processing (Appendix 7), and Ecosystem Metabolism (Appendix 8). The detailed technical findings for each discipline are found in their respective appendices to this report and have been provided on our website (<http://www.stroudcenter.org/research/MooreFdnPeru/index.htm>). The following is a series of questions regarding important conservation issues facing the Madre de Dios region and answers based on insights gained from this study:

1. Can streams and rivers in the region be broadly classified for conservation purposes? If so, are certain characteristics more important than others with regard to conservation?

Answer: Yes on both counts.

- a. Streams and rivers fall into three major biogeochemical categories with distinct microbial communities associated with each: (1) Clearwater [low levels of dissolved ions, dissolved organic carbon (DOC) and fine suspended solids (FSS)]; (2) Blackwater (low levels of ions and FSS but high levels of DOC); and (3) Whitewater (intermediate levels of DOC and high levels of ions and FSS). Conservation workers and others can distinguish among these three types visually and/or with simple field instruments.
- b. Most small streams in the region have unusually low levels of nutrients but high levels of nitrogen as ammonia. This combination makes them vulnerable to oxygen depletion if exposed to excess nutrient loadings associated with human impact. QLAJOYA, which can support virtually no living organisms and is dangerously toxic to humans, is a case in point.
- c. Because of the low nutrients and low in-stream algal production caused by heavy shading, organic inputs from the riparian forests, such as leaves, wood, fruit, and seeds, dominate the food base, metabolism, and type and abundance of aquatic animals of most natural streams in the region. This means that maintaining the quality and quantity of

riparian forest cover is a critical conservation priority throughout the region because it will help sustain the natural food web of the stream.

- d. Nutrient uptake in natural forested streams was lower than in most undisturbed temperate streams, which suggests that the local streams are highly vulnerable to anthropogenic impacts from farm fertilizers and sewage inputs.

2. Does the presence and abundance of “keystone” terrestrial animals (jaguars, monkeys, tapirs, macaws) accurately indicate the health of a watershed and its water resources and/or the degree of conservation success in the region?

Answer: Not always.

Watersheds containing an abundance of these keystone animals had streams indicating poor watershed health and/or on-going pollution. For example:

- a. A stream (QTRC4) in the “pristine” Tambopata reserve was relatively clean and natural in most respects but had concentrations of one pesticide (Chloropyrifos) that were higher than QLAJOYA, which is heavily polluted by contaminants from Puerto Maldonado.
- b. A stream (Q2MIRADORCICRA) in the “pristine” Los Amigos Research Center and Conservation Concession was missing more than half its pollution-sensitive macroinvertebrate species. This indicates severe watershed disturbance, which could be either on-going or historical.
- c. A stream (QATI8) associated with the relatively “pristine” watershed near the ACEER-Inkaterra research facility had the second highest concentrations of the herbicide Atrazine measured in this study.

Since the forest food web depends on fresh water, it is likely that such water contaminants will accumulate in the terrestrial food web and place animals in the highest levels (e.g., keystone taxa) in jeopardy.

3. Can the chemistry of the water give us a good indication of water quality and the type of human impacts in the watershed?

Answer. Yes.

- a. High ion and nutrient concentrations reflect high human impact in the region (case in point QLAJOYA with the highest level of degradation and human impact as well as the highest ion and nutrient levels).
- b. The ratios of ammonium nitrogen to total dissolved inorganic nitrogen (DIN) were higher at sites receiving sewage or manure inputs.
- c. Stable nitrogen isotopes ($\delta^{15}\text{N}$) of nitrate and of fine particulate organic matter at most agricultural sites revealed enrichment due to both manure and sewage inputs.

4. Are there specific aquatic animals whose presence and abundance indicate overall water/watershed health and potential for supporting viable populations of “keystone” terrestrial animals?

Answer: Yes.

- a. Streams containing four out of five of the following aquatic macroinvertebrate groups [crabs (*Grapsidae*), mayflies (*Campylocia*), stoneflies (*Anacroneturia*), and two caddisflies (*Phylloicus*, *Triplectides*) always drained watersheds containing keystone terrestrial wildlife.
- b. All study streams lacking three or more of the five aquatic groups were associated with highly impacted watersheds.

5. Do water quality data that indicate watersheds incapable of supporting important wildlife also indicate high risk for human health?

Answer: We think so – but on a case-by-case basis.

- a. Pesticides found in three streams at levels toxic to aquatic life are also carcinogenic to humans.
- b. Fecal steroid ratios indicate that QLAJOYA is contaminated with human waste, and the level of fecal steroids indicates that dangerous human pathogens are also likely to be present.
- c. Some streams have high fecal steroid levels of non-human origin, but do not have dangerous levels of human pathogens (e.g., QABEJITA, whose fecal steroid ratio indicates contamination from cattle).

6. Can small pockets of human activity broadly jeopardize watershed health and hence on-going conservation activities?

Answer: Yes.

A very small stream (QINF3), which drained a small banana plantation, contained exceptionally high concentrations of the insecticide Chlorpyrifos and the fungicide Metalaxyl, whose negative influences are transported downstream to other parts of the watershed.

7. Does urbanization have a greater impact on water quality than agricultural development?

Answer: Both types of land use can severely impact a stream and often occur together.

- a. An urban stream (QLAJOYA) had elevated concentrations of every pesticide and PCB measured and a 100% loss of pollution-sensitive species, both of which indicate severe impact.
- b. An agricultural stream (QINF3) had significant levels of insecticides and fungicides and an 80% loss of pollution-sensitive species, both of which indicate severe impact.
- c. Stable nitrogen isotopes ($\delta^{15}\text{N}$) of nitrate and of fine particulate organic matter (FPOM) at most agricultural sites show the characteristic enrichment of both manure and sewage inputs.

8. Should best management practices (BMPs) and policies, such as riparian forest buffers, which are common in temperate zones, be an integral part of watershed conservation efforts in neo-tropical watersheds?

Answer: Yes, the region needs policies to protect the riparian forest. However, because they can reduce but not eliminate loss of water quality and impairment of stream health, BMPs should not be used as an excuse to open conserved areas to development.

- a. QINF5, whose watershed is partially deforested for cattle and row crop agriculture but has a wide and intact riparian forest along most of its length, had levels of pollution-sensitive taxa comparable to streams in conserved areas.
- b. QABEJITA, whose watershed is largely deforested for cattle pasture, was able to retain 40% of its pollution-sensitive taxa and most of its ability to process nitrogen and phosphorus by keeping intact a 5-10 m riparian buffer.
- c. Stable carbon isotope ($\delta^{13}C$) of fine particulate organic matter at QKM14 stream suggests that the partial removal of riparian forest along its length has already increased the relative abundance of algae in the stream's food base relative to heavily shaded conserved streams – arguing for a policy to assure the long-term integrity of riparian forest in the region.

9. Beyond global warming and impacts associated with increased UV radiation, are the watersheds, and their human and wildlife populations, at risk from exposure to toxic substances via aerial transport from industrial areas in South America (hence the need to conserve elsewhere in the region to assure success) ?

Answer: This does not appear to be a problem based on our preliminary study

- a. PAHs, which are carcinogenic compounds from petroleum and combustion-generated soot, were uniformly low in all streams – and below all USEPA toxicity criteria for water quality. (For perspective, the Stroud Center recently studied 180 streams supplying drinking water to New York City and found 54 of them to have PAH levels exceeding the EPA water quality guidance values.)
- b. Pesticides in some study streams throughout the region were undetectable (note: the study did not look for bioaccumulation of pesticides in the tissue of key wildlife.)

10. Do conserved watersheds contain high levels of aquatic biodiversity? Is the biodiversity unique? And can it play a critical role in measuring water quality and watershed health in the region and in gauging conservation success?

Answer: Yes on all counts.

Biodiversity

- a. Our 12 most extensively studied small streams contained 204 macroinvertebrate taxa (mostly genera).
- b. 50% of the macroinvertebrate taxa were found in only one or two streams – suggesting a high level of both alpha and beta species diversity.
- c. The microbial survey, which was the first of its kind in the Amazon basin, revealed distinct bacterial communities in the blackwater and clearwater streams of the conserved areas.

Uniqueness of Biodiversity

- a. A significant percentage (> 30%) of macroinvertebrates collected appear to be new species to science.
- b. It appears that the microbial community specializing in processing ammonia (a common chemical in Andes-Amazon streams) is not composed primarily of Bacteria (as in non-tropical streams) but rather Archaea (microbes that look like bacteria but are genetically distinct).
- c. The failure to detect bacteria in the ammonia processing community of the Andes-Amazon streams, if confirmed, would represent an important and novel observation in the field of microbial stream ecology and would help increase the capacity of microbial ecologists working in the Moore Foundation's marine program to understand what is emerging as an important issue.

Role in water quality monitoring

- a. Macroinvertebrate groups sensitive to pollution in the Andes-Amazon region (e.g., mayflies, stoneflies, caddisflies, hereafter the "EPT" group) appear to be similar, but not identical, to those that the Stroud Center has worked with elsewhere in Latin America and the temperate zone.
- b. The extinction of pollution-sensitive macroinvertebrate taxa (EPT) from a stream ranged from 100% (highly polluted stream in the town of Puerto Maldonado) to 0% (a pristine stream in a conservation area), with most clean streams in the region losing less than 20% and most polluted streams losing more than 50%.
- c. The presence of five aquatic macroinvertebrate animal groups (Grapsidae, *Campylocia*, *Anacronuria*, *Phylloicus*, *Triplectides*) consistently seems to indicate very high water quality.

Gauging conservation success

Loss of EPT taxa indicates that some streams (e.g., Q2MIRADORCICRA) in conserved areas are not healthy and that their watersheds are either suffering from a legacy of previous impacts (and need pro-active restoration) or are in need of better and more widespread protection.

11. Is the approach to water quality monitoring in the Andes-Amazon region and the knowledge gained about its value to help plan, guide, and evaluate watershed conservation applicable elsewhere in the neo-tropics?

Answer: Yes.

For example, on December 17, 2006, Bern Sweeney, director of the Stroud Water Research Center, arrived at "Nectandra," a neo-tropical cloud forest preserve in Costa Rica (www.nectandra.org), just after having finished leading a weeklong series of water quality monitoring workshops as part of a Moore Foundation grant on Costa Rica's Osa Peninsula. He had come to Nectandra at the request of its president, Alvaro Ugalde, and co-founders, David and Evelyn Lennette of San Francisco, CA. The Lennettes had purchased 99.9% of the Nectandra watershed in 1999 and had built and furnished a magnificent education/research center focused on conserving the virgin cloud forest and its jaguars, tapirs, and other native wildlife. Sweeney was asked to confirm the purity of the water of a stream called Quebrada

Verde, in anticipation of using it for education purposes and for growing organic rice as a demonstration of sustainable agriculture. Employing the same macroinvertebrate sampling techniques he had taught his Moore Foundation students the week before, Sweeney determined almost immediately that the stream ecosystem was “dead” as a result of heavily polluted sediments and probably toxic chemicals in its water. These pollutants came from a tiny parcel of upstream land that the Lennettes did not own and which was used for growing ornamental plants for market. In subsequent visits that day to nearby streams whose watersheds were completely within Nectandra’s conserved area, Sweeney found water of consistently high quality. Thus, his quick and simple stream survey not only provided a direct measure of Nectandra’s conservation success, but it also revealed the immediate need to acquire the tiny piece of the watershed that was being poorly farmed and whose contaminated water and soil was washing into Q. Verde.

Output 3. Disseminate training workshop and monitoring research information.

What we did

The Stroud Center has disseminated – and continues to disseminate – its monitoring and research information in three primary ways:

1. The Series of Workshops in Madre de Dios, Peru, and the Osa Peninsula, Costa Rica. Not only did these workshops directly reach 153 people in two distinct tropical regions, but the participating groups were selected precisely because they are in positions to disseminate broadly the knowledge, information, and techniques they acquired. A fundamental part of the mission of each participating group – eco-tourism guides, public and private decision makers, teachers, and conservation and NGO staff – is to educate people about the importance of natural resources and to show them ways to practice good stewardship.
2. New Collaborations and Initiatives. Our scientific baseline studies and associated education programs and workshops attracted several key people who will collaborate in our effort to increase local, regional, and international recognition of the critical need to understand, protect, and restore freshwater resources. Four brief examples:
 - a. Jose (“Joey”) Kechlin is the founder and chief executive officer of Inkaterra, Peru’s foremost travel company, which has been operating since 1975 and hosts more than 65,000 clients each year. As part of its statement of commitment, Inkaterra promotes “Conservation and scientific research achieved through self-supported sustainable tourism respecting authentic cultural, social and environmental values.” In addition to the for-profit corporation, Mr. Kechlin created and operates Inkaterra Association (ITA), a non-profit organization, “which promotes the conservation and protects the biodiversity of the Peruvian Andes and Amazon Rain Forest.” Jose Kechlin attended one of our workshops, and at a reception he hosted afterwards for the other attendees, he gave an effective and impassioned plea for the protection of the region’s resources and, in particular, of its streams and rivers. As a major employer, the chairman of the Hotel Society of Peru, a member of the board of the National Chamber of

Tourism, and a long-time emeritus board member Conservation International, Joey Kechlin is in a position to help us spread our knowledge on a broad scale and has expressed a strong desire to do so.

- b. Nigel Pitman is the science director of the Amazon Conservation Association (ACA) and was the Stroud team's host at ACA's field station at Los Amigos, Peru, which he directs and where we carried out several days of research in August. As a result of our work at Los Amigos and conversations with staff there, Dr. Pitman and several of his employees attended one of our workshops. This, in turn, led to an invitation to help design and implement a baseline study of water quality and sampling stations to be included as part of the new infrastructure that ACA is developing in a large sub-watershed of the Los Amigos research concession of Peru.
 - c. Rita Colwell is former director of the National Science Foundation and is currently Chairman of Canon U.S. Life Sciences Inc. and a distinguished professor at both the University of Maryland and Johns Hopkins University. She has previously served as Chairman of the Board of Governors of the American Academy of Microbiology and as President of the American Association for the Advancement of Science, the American Society for Microbiology, the Sigma Xi National Science Honorary Society, and the International Union of Microbiological Societies. She is a leading authority on infectious water-borne diseases and is keenly interested in our existing monitoring sites in Peru. Our effort to strengthen neo-tropical conservation efforts with water quality monitoring information has led to an agreement with Dr. Colwell to collaborate on an expanded water-quality monitoring effort that will include infectious diseases of the Andes-Amazon region. The focus of this collaboration is to connect the Stroud Center's measures of water quality and stream health to the incidence of infectious disease organisms, such as cholera, in the water.
 - d. Many conservation workers, representing both the public and private sectors, attended our workshops in Costa Rica. Some of the participants were in positions that enable them to mandate and/or adjust protocols for environmental protection and conservation. For example, Miguel Madrigal Hernandez, the Director of the Osa Conservation Area for MINAE (Ministerio de Ambiente y Energia), was so impressed with what he learned that he urged his employees and others to attend subsequent workshops during the week, expressed a willingness to endorse the participation of other MINAE workers in future workshops, and requested information that will allow him to add water quality monitoring to the routine task list of the guards employed by the national park system.
3. Website. The third method of dissemination and the one with the broadest reach is our website (<http://www.stroudcenter.org/research/MooreFdnPeru/index.htm>). Table 1.1 in Appendix 1 lists the information that is currently on our website, which will be updated as new information comes to our attention. We are also working with all the organizations and institutions we invited to our workshops (Table 1.2, Appendix 1) to

provide links to our website. We are emailing all the workshop participants who have email addresses, alerting them to the resources on our website and inviting them to become ambassadors for their watersheds by spreading the word as broadly as possible. And we are working with ACEER, ACA, and other groups to expand our reach, both in the region and beyond.

Why we did it

We believe it is critical to get the results of our information about water conditions and the tools for assessing and monitoring stream health to the broadest possible audience. That was our assumption before we embarked on our work in Peru and Costa Rica, and it was reinforced by our experiences on the ground in both places. Moreover, the results of our research and the lessons of our workshops not only have important implications for the residents of the areas in which we worked, but they are also part of a global discussion about water issues. In particular, the message of the vital connection among the protection of small streams, the health of the water supply, and the preservation of large tracts of intact forestland is one that has been at the center of our research, education, and public outreach for almost two decades. Because of our work with groups across North America and other parts of the world, our website has become a significant source of information on water research, education, and monitoring.

What we found

1. **Issues facing the region.** The Madre de Dios region – and particularly the area of the confluence of the Madre de Dios and Tambopata rivers around Puerto Maldonado – is on the verge of enormous and potentially devastating changes. Supported by both private land development efforts and public policy, the region’s population has grown by almost 50% in the last decade and has tripled since 1981. Most of that population growth has taken place in the capital city of Puerto Maldonado, but the rapid expansion of agriculture and gold mining has brought substantial deforestation since 1990. That, however, will pale in the face of the Acre-Musako highway and bridge currently under construction. While much of the discussion around the new road focuses on commercial development, the principal impact will come from the projected tenfold, 120,000-hectare, increase in land under cultivation, which account for 45% of the expected economic benefits of the project. Needless to say, land speculation is rampant in the region. Our research in other areas of the world has demonstrated the clear connection between population growth, deforestation, agricultural activities and road building, and the degradation of a region’s streams and rivers. Particularly vulnerable are the small streams, whose critical importance is often overlooked by those who readily see the value of the big rivers, which supply transportation, hydropower, food, recreation, habitat, etc. But small and medium-sized streams provide more than 90% of the overall water supply, and their protection is essential to the health of the entire system.
2. **Ecosystem services.** While the economic value of gold mining, agriculture, timber extraction, and tourism are well understood, the substantial economic benefits of clean fresh water are often overlooked. When, for example, we asked the students who came to our August workshop where their fresh water came from, the answer was “the treatment

plant.” Moreover, the participants in the fall workshops had very little understanding of the importance of protecting small streams, the vulnerability of Puerto Maldonado’s water supply due to the location of the drinking water intake pipe, the relationship of forest protection and clean water, or the availability and use of accessible methods for monitoring water. But they were anxious to learn about the quantifiable value of clean water to human and animal health, to the eco-tourism industry through the protection of food sources, water supplies, and wildlife habitat, and to reducing the costs of treating drinking water and cleaning industrial equipment.

3. **Human health.** From mercury contamination to water-borne diseases to sanitation problems, the connection of clean water and human health was very much on the minds of those who attended our workshops. Several nurses and six staff members of the Ministry of Health came out from Puerto Maldonado and made clear to us the need to continue the work we were doing, both in assessing and monitoring the water sources and in educating people about the issues.
4. **Major impacts.** There is a great deal of concern about the two major impacts on the region’s water: (a) gold mining and the mercury contamination that accompanies it; and (b) the transcontinental highway and the population growth and land development it will bring. The information we conveyed about the current state of large parts of the watershed, the pristine small streams that have to date been little affected by human impact, and the critical role played by the large areas of preserved and protected land made a huge impression on the workshop participants. They asked for more information; they grasped the value of the monitoring techniques they learned in the stream and laboratory; and they requested future workshops to alert and teach others.
5. **Rainforest protection.** There exists a strong connection between protecting the water sources of the Amazon headwaters and preserving its rain forests – a connection that has both ecological and economic components. As the Stroud Center’s research in temperate streams has clearly demonstrated, streamside forests play a vital role in protecting a stream’s health by enhancing the ability of its ecosystem to process organic matter and pollutants. The deforestation of riparian lands compromises both the quantity and the quality of the stream’s ecosystem and reduces its ability to deliver important services to humans. In their most recent study of 16 streams in eastern North America, Stroud scientists found that stream sections flowing through forested areas are wider and shallower than those in meadowlands, their beds are rougher and have more habitat, and water moves more slowly through them. These factors, along with other riparian forest benefits, such as a greater variety of organic food and more natural temperature patterns, produce a richer and more natural ecosystem than do deforested streams, and the increased abundance of bacteria, algae, invertebrates, and fish enables them to better process certain pollutants. Moreover, the streams that the rainforest protects in turn provide essential habitat, food, and water for the flora and fauna of the forest itself. The economic value of this symbiosis – for ecotourism, for human health, for savings in water treatment costs – is enormous, and the costs of compromising the health of the ecosystem would be devastating to the region and beyond.

6. **From local to global: issues for a world in crisis.** Coming on the heels of the 4th World Water Forum in Mexico City on March 21st and 22nd, 2006, which “reaffirm[ed] the critical importance of water, in particular fresh water, for all aspects of sustainable development . . . and underline[d] the need to include water and sanitation as priorities in . . . national sustainable development and poverty reduction strategies,” our work in Peru and Costa Rica is part of a global effort to give people and their governments the tools they need to protect the sources of clean water – and the human health that is dependent on that water. We see our work as an important step in an ongoing process to protect one of the world’s most critical and vulnerable resources – fresh water – in one of the world’s most critical and vulnerable environments – the Amazon rain forest.