When and where is a PWS investment justified in biophysical terms?

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There is growing interest to protect water resources throughout the world. One mechanism that is being proposed by organizations and individuals interested in conservation of natural ecosystems is the direct payment to landowners for better and more sustainable land management practices, otherwise referred to as Payment for Ecosystem Services (PES). As water companies, governments and the general public promulgate the importance of forests for water flow and quality, payment schemes in many cases are based on the "promise" of protection. The corresponding scientific evidence is not always being developed to substantiate the claim.

Due to the complexity of land and water relationships and limited data and research, there is a lot of debate among specialists on the hydrological services offered by different ecosystems. There is contradictory evidence on the role of forests to water flow and quality, and a lot of the information seems to demonstrate how risky generalizations can be. A quick review of the literature can lead to conclude that all impacts are site specific. Yet in the field, there is a lack of reliable data and resources (time and money) to do the corresponding research. Decisions need to be made, despite the uncertainty. Science can provide some answers but it is important to develop data gathering and monitoring processes that are cost-effective and can evolve overtime, as practitioners of innovative mechanisms evolve in their own learning curve (Tognetti et al. n.d). Decision support systems would help in such a situation, but their complexity limits access to non-specialists and local policy makers (Hayward 2005).

Therefore, this document attempts to simplify the information available on hydrological services of forests and other natural systems. Specialists maintain that there can be no generic rules that apply to all situations, so it is very important to keep in mind the specificity of each case. Supported by the Tropical America Katoomba Group (TAKG)[1], this document aims to summarize for practitioners what has been published as potential land use practices and hopefully help to better focus hydrological data-gathering and research efforts. Due to the regional focus of the TAKG, emphasis will be given to information relevant to Latin America. Information maybe available that is not reflected in this document, so readers are invited to present comments and new sources of data.

The document is divided in five sections. Initially, a general description of the potential hydrological services that have been identified and documented. Then sections two through four presents the data categorized on the certainty of the hydrological impacts of particular land use practices:

a) situations when there is <u>no doubt</u> that you can contribute to hydrological services,
b) situations when there is a <u>high probability</u>, and
c) situations when there is a <u>50% chance</u> of contributing to hydrological services.

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[1] The Tropical America Katoomba Group (TAKG) is a network of PES practitioners, academics, government officials, community members and other stakeholders interested in advancing compensation and payments for ecosystem services (CES / PES) in Latin America by supporting the creation of favorable legal, political, organizational and learning environments. www.katoombagroup.com

Therefore, with greater uncertainty, PES proponents have to spend more time and resources providing better information and research to justify their scheme. An appendix that describes some of the hydrological tools available is included.

Finally, section 5 summarizes some "rules of thumb" that were identified in the literature and can aid practitioners in designing their PES schemes and their corresponding hydrological monitoring systems.

Section 1: How compelling is the argument that investment in watershed protection is scientifically justifiable?

The amount of water available in a watershed is the amount that can be stored in vegetation and soils and released at different time lags in streams and rivers. Tongetti et al. (n.d.) represent this by the formula:

$$\Delta S = P - Q - AET - G$$

Where, ΔS is the change in storage, P is precipitation, Q is Streamflow, AET is Actual Evapotranspiration, and G is loss to deep-water aquifer not accounted for by streamflow.

The amount of rainfall and water that seeps to the aquifer are predominantly determined by climate and geological conditions, beyond human influence. Actual evapotranspiration is a function of numerous variables (precipitation, temperature, solar radiation, soil type, drainage, wind, canopy and understory interception, and vegetation type and maturity). Though difficult to measure, actual evapotransporation can be influenced by land use practices that affect vegetation and soils. Water availability depends on soils (porosity and depth), and the depth of the roots of the vegetation to reach the water table. Old growth forests, tree plantations, homogeneous tree crops (oil palm and rubber trees), pastures and annual crops all have different root depths and thus, provide different hydrological costs and benefits (Montagnini, et al. 2005). Therefore, planners need to know land use patterns in the watershed in order to understand the hydrology. Type of vegetation and its corresponding soil management practices are important consideration when discussing hydrological impacts. Yet, as this document will highlight, it is NOT THE ONLY consideration.

In theory, hydrological services provided by natural forests or native vegetation may include the following (Bruijnzeel, 2004 and Bruijnzeel and von Noordwijk 2007):

- Optimum stream flow: refers both to total yearly amount, as well as flows during the dry season (dry season flow);
- Maximum soil protection: allows for optimum regulation of seasonal flows, meaning more water in the water table during the dry season (prevents droughts) and less excess runoff during the wet season (prevents floods);
- Optimum water quality: forests and their optimum soil conditions can prevent hill slope soil erosion and thus sediment loads down stream. Also, native vegetation along riversides can filter some biological (domestic and animal) and chemical (agricultural) discharges and improve the stream´s capacity to purify the water. In addition, riverside vegetation can serve as habitat for wildlife and flora;
- Optimum nutrient productivity: leaf litter and wood debris can be sources of nutrients for aquatic biodiversity.

Hydrological effects of land use practices will vary depending on the following characteristics:

- Soils (types, depth and conditions)
- Geological substrate
- Topography (slope, ruggedness of terrain)
- Rainfall patterns (amount over time, vicinity to coast – influence of ocean currents)
- Composition of vegetation - species
- Forest management practices (logging measures, roads, equipment, etc.)
- Land use patterns (upland development patterns)

- Water management practices (dykes and infrastructure, use, etc.)

Effects are strongest nearby (<10 kms^2) but will be less visible at greater distances. In addition, there are lag times between land use change and its hydrological effect making cause and effect relationships more difficult to assess.

There are some common misconceptions about forests and trees, which several authors have attempted to clarify in other to prevent negative environmental impacts (Bruijnzeel 2004 and 2007, Calder 2005, IIED n.d.):

- DEFORESTATION CAN LEAD TO MORE WATER FLOW:

Trees need water to grown and they move it through their system and release it as evotranspiration. Therefore, they absorb and release water constantly at different rates in their growing cycle. The usual good capacity of soils to absorb water under natural forests or vegetation, rather than the vegetation itself, can stabilize water flows throughout the year. Subsequent land use patterns after deforestation tend to further deteriorate the soil's infiltration capacity and allow more water to flow, ranging from 100 to 800 mm depending of the percentage of area affected and rainfall patterns. This can be beneficial from the stand-point of consumers down stream.

The "sponge" effect of forests, a long-lived theory that has justified many reforestation projects worldwide, has been strongly questioned in the last decade. Since trees need water to grown, reforestation will not provide more flow of water. Therefore, promotion of tree-planting, particularly evergreen fast growing species which use a lot of water will not increase flows, and even less so in dry areas.

- WEATHER PATTERNS, NOT TREES, DETERMINE RAINFALL:

Climatic conditions determine rainfall patterns (Hayward 2005). Evidence of forests incidence on rainfall have been found only in very large watersheds, such as the Amazon or Congo rivers.

- FOREST COVER CAN REDUCE OCURRENCE OF LANDSLIDES OR FLOODS:

Extreme events, such as deep landslides or floods, are determined by climate, topography, rainfall and soil (geology) conditions. Therefore, a good forest cover does not insure that they will not occur. However, their frequency of occurrence will be less compared under conditions of forest conversion (Bruijnzeel, 2004).

Section 2: When and where is there virtually no doubt that you can contribute to hydrological services?

- **Protecting wetlands**: Wetlands provide the following services:
- water recharge, because of their storage capacity
- water quality, act as filter to allow slow decomposition of pollutants and control sediments,
- flood control

In addition, wetlands are key habitats for wildlife and aquatic diversity. Houlahan and Findlay (2003) found that the effects of adjacent land use on amphibian species richness and community composition were strongest at around 200 meters but effects peak at 2000–3000 meters. Chan et al (2005) found evidence of synergy between biodiversity and water provision and flood control services in California as found in the literature for Yangtze River watershed in China, around the Panama Canal, and in the Catskills and Charles River watersheds, in the US.

Therefore, wetlands need to be protected always and usually never are. They are usually considered useless “swamp lands” justifying draining them completely. In tropical areas, where water availability depends on rainfall, which is seasonal in nature, the natural storage capacity is important and wetlands can provide that. The average flow in a river, also known as baseflow, depends on the geomorphology and landuse of the catchment (Tognetti et al. n.d). A common practice to protect wetlands is to provide buffer zones. This can be an effective initial measure but it maybe ineffectual if a large area of wetlands is intervened. Houlahan (2004) found that rather than focusing on the buffer zone, better to focus on maintaining a mixed regional landscape of natural forests and wetlands.

- **Maintaining riparian buffer zones**:

Vegetation near and beside rivers and streams can reach water easily and play a similar role than wetlands by providing:

- water recharge, roots can easily reach the water table,
- water quality, act as filters to allow slow decomposition of pollutants and control sediments,
- flood control.

- **Protecting high altitude grasslands**: Cloud affected ecosystems, such as *páramos*, are excellent water producers because of a combination of factors:
- High precipitation, including wind driven rain,
- Vegetation captures surrounding fog (horizontal precipitation),
- Low water use, due to fog conditions,
- High organic matter content in soils, increasing their filtration capacity.

Throughout the Andes, these areas have been used as common lands for pasture with the corresponding practice of burning to regenerate the grasses. The combination of burning and overgrazing affects the infiltration capacity of the soil reducing storage capacity. Studies are few --INCOMPLETE

- **<u>Control upland development for improved water quality</u>**:

Tognetti et al. (n.d) highlights that "the impacts of landscape management on improved water quality and reduced sediment are felt at larger scales (an order of magnitude of 4 for nutrients) than the hydrologic changes." Land use management practices that can either:

a) increase infiltration by preventing permiabilization of soils, such as building roads or urban settlements or poor agricultural practices,
b) reduce soil moisture by increasing deep rooted vegetation (trees), but this takes time.

A review of the literature (Aylward 2002) generally confirms that land use change, especially the loss of forest cover, results in:

- Increases in sediment yield as well as the flow of chemicals and nutrients

Slope and topography of the landscape provide zones that dissipate (and allow sediment to settle) or accentuate runoff momentum.

In addition, hillslope processes can have other collateral effects than water quality which can affect response to wet periods, and increase risks of disasters. Roads can intercept groundwater recharge and divert it to streams, contributing to increased peak flows. Although unpaved paths or roads may occupy a small area of a basin, compared to agricultural use for example, its been found to contribute a similar amount to a watershed's runoff and stream sediment (Tognetti et al. n.d).

Section 3: When, where and how is there high probability that you can contribute to hydrological services?

- **Protect montane cloud forests**: Found between 1,500 to 3,000 meters above sea level in continental areas, and around 500 meters in islands, present a combination of the following factors that can increase flow by up to 10%:
- High precipitation, including wind driven rain,
- Vegetation captures surrounding fog (horizontal precipitation),
- Low water use, due to fog conditions.

These forests are found in a wide range of countries, including many countries in Latin America, Tanzania and Malaysia and home to high variety of species, particularly amphibians and epiphytes.

A recent watershed study funded by the United Kingdom Department For International Development (DFID) described in the appendix in the Arenal region of Costa Rica, compared two areas, one forested and one converted to cattle pasture. The results can be summarized as:

- Though total annual streamflow was not different between the two sites, lower (to non-existent) dry season flows were found under pastures.
- Cloud forests flow regulation also contributed to reduced erosion and subsequent sedimentation downstream.
- Cloud forests on slopes in highly fractured terrain can intercept rain driven rain and feed it to the system, as run-off or groundwater recharge, and thus contribute to downstream users, justifying a PES scheme.

Though the water gain from montane forests may not be significant, around 10%, it comes at a time of the year when water is needed most. Therefore, its relevance needs to be highlighted. In addition, soils in cloud forests tend to be very permeable and easily eroded, so the risks to from deforestation are high.

> The documentary Mountains in the Mist, made by Sampurno Buijnzeel and Halsundbeinbruch Film from Switzerland, is a educational documentary on the biodiversity and hydrological services provided by Cloud Forests in Costa Rica. Can be ordered at www.halsundbeinbruch.ch.

- **Hillside soil protection practices**: Land management practices that encourage infiltration in the hillsides can recharge baseflow. Traditional practices, such as detention basins on the hillsides and the construction of filtration galleries that assist in collecting percolation water have been highly successful in improving springs which recharge the fractured bedrock aquifer (Tongnetti et al . n.d.).

Other measures have been discussed in the literature, that can also be effective include:

- Soil protection measures such as, grass barriers/ditches, contour trenches and terraces, can reduce soil loss and increase infiltration;
- Agroforestry or low density tree networks can increase permeability of soils without excessive water consumption by trees.

Section 4: When and where is there a 50-50% chance that you can contribute to hydrological services?

- Due to the complexity of land-water linkages**, flow services (total yield or seasonal – dry and storm- flows)** are often site specific, and require detailed studies and modeling. It maybe necessary to do a pilot project before doing large scale implementation in order to be able to provide the hydrological service. Evidence demonstrates that vegetation can improve the flow by increasing the permeability of the watershed. In contrast, water use by vegetation can reduce availability of water to streamflow (Calder 2005, Bru

Three key factors affect flow, which are important to consider (Tognetti et al n.d., IIED n.d.) to evaluate where land use can influence:

i) Permeability determined by vegetative ground cover, soil depth and soil texture, but to quantify the impacts of landuse management on groundwater recharge, requires surveys and studies, or modeling by specialists;

ii) Access of roots to water going to the aquifer, which in turn maybe used by the deep rooted vegetation and not be available to flow;

iii) The hydraulic properties of the contributing aquifer for the most part, watershed management does not impact. Although severe soil loss can have adverse impacts on storage capacity.

In regards to dry season flow Tognetti et al. (n.d) sums it up as: "It is not a myth that forests improve the permeability of a soil horizon increasing the amount of water that can be stored. The myth is that gains from additional infiltrating water are available to streamflow. More likely than not, the forest itself will transpire much of it unless a flow path can be established beyond the reach of roots, such as in fractured bedrock rock or very deep permeable soils."

Another potential hydrological service is the reduction of storm runoff volume, which has been found to be significant in most small watersheds in less extreme events. Besides reducing risk of floods, storm runoff constitute a serious risk to water quality and increases the transport sediments.

Section 5: Some Rules of Thumb

⇒ Water runs downhill. What humans put on the land, or in the air, it will likely end up in the water eventually .
(www.sciencenetlinks.com/lessons.cfm?DocID=275)

⇒ Total water yield is proportional to area deforested
(Bruijnzeel 2004)

⇒ In smaller watersheds, there is increased risks of negative hydrological impacts
(Nelson & Chomitz 2004)

⇒ With greater proportion of watershed deforested, risks of negative hydrological impacts increases
(Nelson & Chomitz 2004)

⇒ On steeper slopes, there is increasing risk of negative impacts
(Nelson & Chomitz 2004)

⇒ Impacts of land use on the water balance are therefore expected to be more significant in catchments with significant soil cover since the accessibility to water in shallow soils is similar for plant species with deep and shallow roots, whereas deeper soils will exclusively supply plants with deeper roots.
(Tognetti et al., n.d.)

⇒ Market mechanisms that relate land management to streamflows requires validation at the scale of action
(Hayward, 2005)

⇒ Land use induced change on the hydrologic regime is perceptible up to 3 orders of magnitude larger than the scale of management.
(Tognetti, n.d. from Kiersch 2000)

⇒ As a general rule, land use impacts on flows of water and sediment are best examined and addressed at the level of individual hill slopes and patches, which are the source of significant landscape and land use heterogeneity that affects flow routes. In contrast, water quality and water diversions can be detected and impacts felt at basin scales, at which they are more appropriately addressed so as to permit consideration of trade-offs among all affected stakeholders.
(Tognetti, n.d.)

⇒ “Prevention cheaper than restoration”

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