REFORESTATION, WATER YIELD, AND MANAGEMENT OF MICRO-WATERSHEDS IN CENTRAL AMERICA

by

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THESIS ABSTRACT

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In Central America, two conflicting narratives are used to describe the relationship between forest cover and water availability, with implications for management of water resources throughout the region. Many resource managers believe forests increase dry season water availability, but scientific consensus refutes this perspective. This study analyzes the narratives explaining the relationship between forest cover and dry season water yields in Central America and how they influence resource management. In a case study of the Sasle catchment in Nicaragua, I use a combination of satellite imagery analysis and SWAT hydrologic modeling to investigate land use change over the past 25 years and the potential impact of these changes on the hydrology of the catchment. False perceptions of the role of land cover in hydrology are influencing management practices in sensitive headwater catchments and creating unintended results. A broader perspective on the socio-political and scientific context of these narratives is needed.

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To my father, who taught me that science is no excuse for bad writing.
And to my mother, whose belief in me is inexhaustible.

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CHAPTER I

INTRODUCTION

In Central America, as with other parts of the world, forests are considered vital to the health of water systems. A popular narrative likens forests to sponges, describing how they absorb water when it rains and slowly release water to streams during seasonal droughts. Environmental development policy throughout Central America focuses on the protection and restoration of forest systems in part to ensure the quality, quantity, and continuity of water supply, on scales ranging from the national and supranational to the extremely local. Yet despite the widespread adoption of policies supporting forest protection and the scientific consensus that forests are vital to water quality, hydrologic research has demonstrated that forests do not necessarily play the sponge-like role described in the narrative. In fact, they often act more like pumps, removing moisture from the soil and releasing it through transpiration during the dry season. With all the time and resources put towards water resource management in the region, this point of contention is not trivial. What can be made of the disconnect? And what does it matter to water resource management?

My research examines the beliefs surrounding the relationship between forest and water management in tropical forests and brings the dissonance between scientific and popular understandings into focus through a case study of the small Rio Sasle watershed in Central Nicaragua. Through both quantitative and qualitative methods, I analyze the context in which water management is taking place, and how this context fits the physical reality of the watershed and its hydrology. Specifically, I address the following three sets of questions:

(1) How is the role of forests in water management being characterized in Central America by both scientists and policy-makers? How are these characterizations interacting to influence management in the region, and in particular at the scale of Rio Sasle?

(2) What land use changes have occurred in Sasle over the past 30 years, and what is the likely impact of these changes on the hydrology of the watershed?

(3) To what degree are management objectives functioning as intended? How might conflicting perspectives on the role of forests in water management be addressed?

Other studies have examined the existence of conflicting perspectives between scientists and policy-makers over the water-regulating properties of forests (e.g. Kaimowitz, 2005; Kosoy et al., 2007). However, they have not examined this dissonance on an operational scale - that is, by identifying the actual work done by the forest-as-sponge narrative and exploring the social and physical impact of this work on Central American watersheds. My research will attempt to address this gap by focusing on both social and physical forces in the context of a specific place: the Sasle catchment. Through my first research question, I examine the development narratives relevant to water management in Central America and the institutions that create and propagate these narratives. I also investigate how these social forces may be playing out at a local scale. Through my second research question, I consider the physical catchment by examining how land use and hydrology are actually changing. Finally, in my third research question I evaluate how the narratives may be shaping the catchment's physical reality. Furthermore, I inquire how, in light of the findings, water resource management in Central America might be reshaped to better achieve management goals.

Thesis Organization

In the next chapter (Chapter II), I provide background on water management in Central America. I also describe the study location and its relevance to my research questions.

Chapter III focuses on the first research question. In it, I analyze the narratives and discourses in Central American water management that relate to forest cover. I review relevant literature and analyze primary documents produced by aid organizations and resource managers. I use observational research and the results of participatory mapping exercises conducted by myself and others to provide context to these documents. I use this evidence to characterize the policy context in which water management is occurring and hypothesize the possible implications of this policy context.

My second research question, which investigates land use change and its impacts in the Sasle catchment, is addressed in Chapter IV. I quantify land-use change over a 30-year period in the Sasle catchment using Landsat satellite imagery. I also model the potential impact of these changes on catchment hydrology using the Soil and Water Assessment Tool (SWAT).

Chapter V addresses the third research question. I integrate results from my first two questions and speculate on the implications and possible applications of these results to forest and watershed management in the tropics.

CHAPTER II

BACKGROUND

The Context for Watershed Management in Central America

Physical Geography and Natural Resources

Geographically, Central America sits along a narrow isthmus tapering from southern North America between the Atlantic and Pacific oceans. The seasonal migration of the intertropical convergence zone (ITCZ) across the region creates a seasonal wet/dry climate. This volatile, tectonically active zone experiences hurricanes, volcanoes, earthquakes, and landslides. Hurricane Mitch, which struck Central America in 1998, caused thousands of deaths and billions of dollars in damage, particularly in Honduras and Nicaragua. Deforestation and excessive sedimentation are frequently cited as the region's largest environmental issues (Kaimowitz, 2005). Although estimates of deforestation vary, studies have found regional annual deforestation rates to be around 1 percent (+/- 0.5%), with remaining forest being highly fragmented in character (Achard et al., 2002; Mayaux et al., 2005).

In catchments such as Rio Sasle, both water scarcity and water quality are issues affecting human health and well-being. Scarcity is expressed seasonally, making the continuity of water supply throughout the year a primary concern in water management. This issue is especially important in rural areas with limited or no capacity to store water and where people are dependent on the continuity of streamflow for personal consumption and small-scale irrigation.

International Relations

The United States played a heavy hand in Central American politics through much of the 1900s, an era characterized by internal conflicts and civil wars. The decade of the 1980s saw a sharp increase in US aid to the region (mostly in the form of 'security aid' support to Central American governments), a deepening of the economic crises facing Central American nations, and a widening of economic disparities amongst the population (Danaher et al., 1987). The failure of aid policies to achieve appreciable socio-political results or address environmental issues spurred heavy criticism aimed at redirecting this aid to people and the environment (e.g. Danaher et al., 1987; Karliner, 1989; Sollis, 1992). I will argue that it is, in part, the institutional reaction to this criticism that has encouraged the incorporation of non-scientific narratives about forests and hydrology into development policy.

Central America, with the exception of Costa Rica, is still a major recipient of money through global development assistance, both from bilateral and multilateral donors. In the decade from 2000-2009, El Salvador, Guatemala, Honduras, and Nicaragua together received nearly $19 billion (US) in total development assistance (with Nicaragua receiving $8 billion of this) (de Brey et al., 2011). The largest donors to the region are (in order) Spain, the Inter-American Development Bank (IDB), the United States, and Germany. Of the Central American nations, Nicaragua is most reliant on international aid. Official development aid equaled 77% of the central government's gross expenditure in 2007 and 60% in 2009 (de Brey et al., 2011). This dependency on foreign aid has left the region open to the influence of development policies ranging from structural adjustment to the implementation of environmental strategies such as Integrated Water Resources Management (IWRM).

The influence of multilateral agencies and NGOs is pervasive. I was told by a member of an environmental resource agency while visiting a field site of a regional research institute in rural Honduras that that I would be hard-pressed to find a community in the Central American region that had not participated in at least one development or educational program. There are over 3,000 NGOs in Nicaragua and over 9,000 in Honduras, which translates to roughly one NGO for every 2,500 citizens in Nicaragua or 900 citizens in Honduras (International Center for Not-for-Profit Law, 2012a, 2012b). These organizations vary broadly in size, scope and focus, with some international NGOs primarily focusing on the development and dissemination of policy frameworks and other regional and local NGOs doing on-the-ground work (Sollis, 1992). Coordination between multilateral agencies and NGOs has increased substantially since the 1980s (Sollis, 1992). Together these organizations create a structure through which global-scale socio-political forces interact with the local and mundane over issues such as global warming, biodiversity, and global commodity trade.

Study Area - Rio Sasle Watershed

My choice of the Rio Sasle watershed for a study site was largely one of convenience and familiarity. Rio Sasle experiences water scarcity and is a project site for a regional water NGO through which I gained access to watershed tours, participant workshops, and conversations with local experts. It is in the greater Lake Managua watershed and is considered important to hydro-electric production and national fisheries. But these attributes are not unique to Rio Salse. In fact, it is because Sasle is unexceptional that it makes an appropriate study site. The issues relevant to water management in Sasle – water scarcity, poverty, and conflicting land use needs – are all common to many upland watersheds in the region.

The Rio Sasle watershed is located in the high central region of Nicaragua (Figure 2.1). The watershed is small, covering approximately 11 km^2 of land with a main channel length of 7 km. Elevation in the watershed ranges from 1022 to 1368m, and slopes are shallow to moderate, with 15% of the catchment having slopes greater than 30°.

No permanent meteorological stations exist in the watershed, but global precipitation maps indicate approximately 1500mm of rain annually (Figure 2.2) (Hijmans et al., 2005). Higher elevations receive slightly more and lower elevations less. The wet season extends from May through October. Mean monthly low temperatures range from 13-16ºC and highs from 24-27ºC (Hijmans et al., 2005).

Sasle is located within the department of Jenotega. It extends over two formal municipalities (Jenotega and San Rafael del Norte) that are composed of approximately ten individual farming communities. Population in the basin is probably between 700 and 1000 based on estimates of the number of families and average family size (CRS & DAP-USAID, 2006).

People living within the watershed are generally small landholders and most have legal documentation of their landholding, though the cost of such documentation is prohibitive to some families. Residents eat what they grow, travel by foot, car, or bus, and are connected to the outside world through radio. Residents of Sasle have access to good water through a potable water system, but residents of Los Horcones do not. Incomes are derived from sale of both produce and labor. Some residents work across the border in Costa Rica during the seasons between planting and harvest (CRS & DAP-USAID, 2006). Because of limited economic resources, community resilience to environmental change, including decreased water supply, is considered low by the local water resource NGO.

Agricultural production is primarily focused on subsistence crops, with the excess sold commercially. The most important crops are corn, beans, potato, cabbage, and lettuce. The local NGO has reported low harvests in spite of improved agricultural techniques including the use of improved seeds, bans on burning, live barriers, dead barriers, production on contour, and sediment dams. Chemical fertilizers and pesticides are commonly used. Many families also range animals including cows and chickens, but for the most part animal husbandry is very small-scale and the products are for household consumption. Larger commercial interests in the watershed include coffee plantations in the steeper, higher-elevation slopes and cattle grazing in the flatter, lower-elevation zones. Coordination of all residents over issues of land management has been difficult (CRS & DAP-USAID, 2006). Figure 2.3 shows examples of agricultural production conditions in the catchment, including application of pesticides on crops, farming on marginal land, and the use of conservation strategies on steep terrain.

Figure 2.1. Location of the Rio Sasle watershed.

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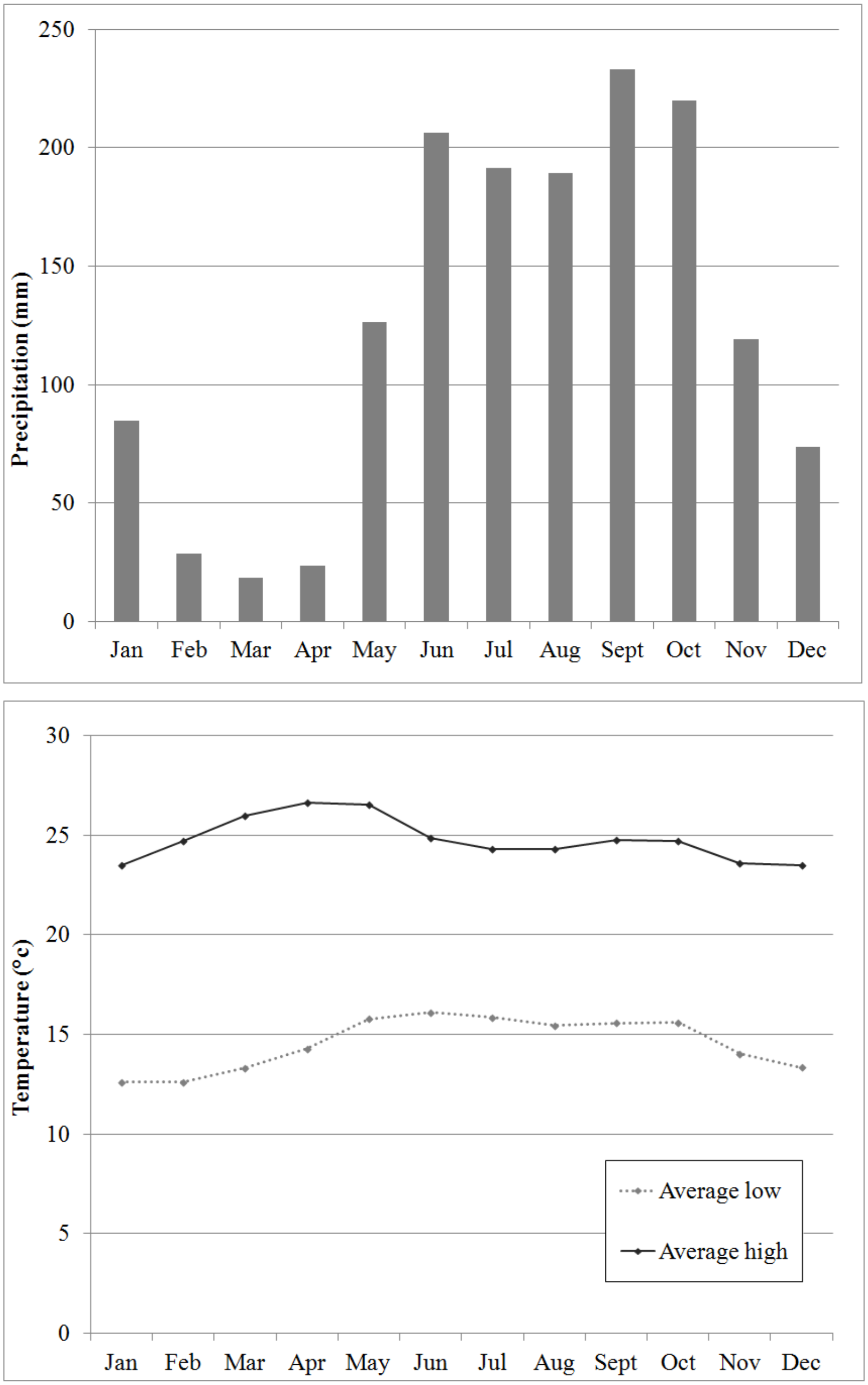


Figure 2.2. Average monthly weather statistics from the Sasle catchment from interpolated WorldClim data (Hijmans et al., 2005).

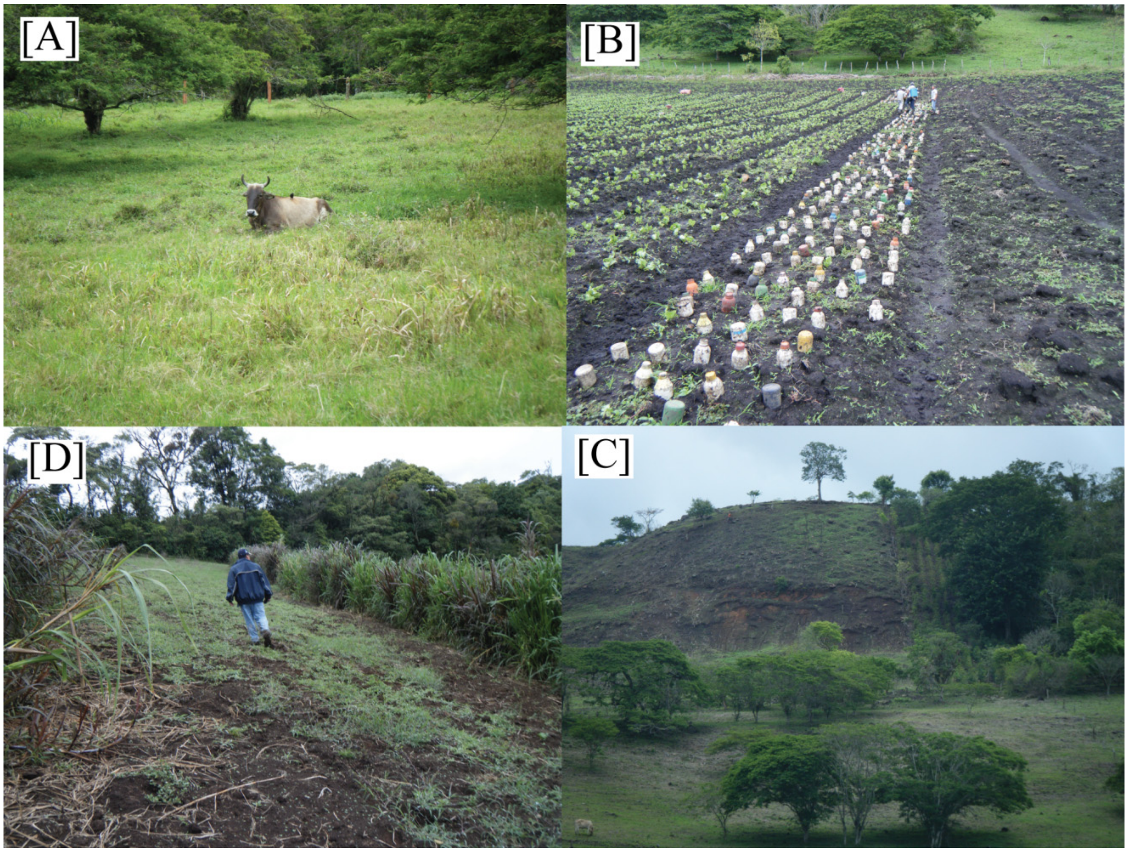


Figure 2.3. Agricultural practices in the Sasle catchment. Clockwise, beginning upper left: (A) Cattle ranging in the lower watershed; (B) Application of chemical pesticides to a garden crop; (C) Corn sown on a very steep hillslope; (D) Use of soil conservation practices (live barriers).

CHAPTER III

NARRATIVES

The Forest Is a Sponge

The ‘forest-as-sponge’ narrative reads something like this: ‘*When rains falls on deforested land, much of the water immediately runs off into waterways and becomes a part of flood flows. Very little is held in the soil and released slowly into waterways in the dry periods between major rain events. This results in more extreme water levels – both during floods and low flows. But a forest is like a sponge. When rain falls on forested land, the water is held in the soil and released slowly into waterways over time. This has the advantage of decreasing rainy-season flood flows and increasing dry-season low flows, thereby preserving homes and property and providing more water for people and agriculture when it is needed most. Reforestation restores these sponge-like characteristics to the land and for this reason is an important policy goal.’*

The wording changes, but versions of the narrative are found all over Central America in the language of management and development projects and in popular depictions of resource crisis in Central America. An example can be found on the Wikipedia page (Wikipedia, March 5, 2012) devoted to water resources management in Nicaragua:

> Deforestation, with its devastating environmental consequences, is a serious problem. Deforestation accelerates soil erosion, decreases the amount of recharge to aquifers by increasing surface runoff, damages barrier reefs and ecosystems, increases turbidity which affects mangroves, decreases agricultural production, and causes increased maintenance of water infrastructure. Decades of land abuse and environmental neglect exacerbated the devastation of Hurricane Mitch (1998), where deforestation played a major role.

Here the narrative shows up in two places: first, by stating that deforestation decreases aquifer recharge; and second, by implying that deforestation exacerbated the flooding associated with Hurricane Mitch.

Another example of the narrative, taken from a special report by an environmental think-tank, the World Resources Institute (1993), reads:

> Humid tropical forests also provide invaluable ecosystem services. They retain soil and nutrients, provide perennial water supplies, and moderate runoff during peak flows in the rainy season. Unfortunately, the value of these services to society as a whole is rarely realized until deforestation diminishes or destroys them. Around the world, tropical deforestation is directly linked to severe flooding, sedimentation, water shortages, decreased hydroelectric production, landslides, and productivity losses in such coastal ecosystems as mangrove forests and coral reefs. (Johnson & Cabarle, 1993, pg 7)

Again, forests are associated with providing year-round water supply and decreasing flooding, while deforestation is linked to an increase in the occurrence of both flooding and water shortage.

Evidence of the narrative can also be clearly seen in the environmental understandings of individuals throughout Central America. Surveys by Kosoy et al. (2007) reveal that over 90% of respondents in three regions of Honduras, Nicaragua, and Costa Rica perceived a positive correlation between the quantity of forest cover and the quantity of water available for consumption. *Zero percent* of respondents in the same survey believed that more forest cover led to less runoff. In this study, the belief that forests increase water availability was stronger than the belief that forests improve water quality.

The main assertions of the forest-as-sponge narrative are that (a) the presence of trees in a watershed increases water supply; (b) this effect is greatest during dry seasons of low streamflow; (c) deforestation decreases the ability of a watershed to produce adequate water supply; and that (d) reforestation restores the water-producing, sponge-like qualities of a watershed.

To many, the narrative may appear ordinary and unsurprising. The story is widespread and alluring to environmentalists and humanitarians alike. But the existence of this narrative is striking because a review of scientific literature reveals a starkly contradictory story. In contrast to the forest-as-sponge narrative, scientific research indicates that a positive relationship between forest cover and water quantity is rare and highly conditional (e.g. Bruijnzeel, 2004; Kaimowitz, 2005). Indeed, the narrative told about forest cover and streamflow by researchers in scientific institutions in the global west is substantially different than what is conveyed by the forest-as-sponge narrative and widely used in policy formulation and land management.

The Narrative of Thirsty Trees

The 'scientific' narrative explaining the relationship between forests and streamflow would read something like this: *'The amount of water flowing in a stream is a function of the inputs (precipitation) and outputs (evaporation and transpiration) of water in the watershed, as well as changes in the amount of water stored, for example in soils and groundwater. Trees use large quantities of water, and therefore represent a large output from the watershed system. The water that trees use is water that cannot end up as streamflow. When forests are harvested or thinned, there is less demand on water in the catchment and annual surface runoff from the catchment increases. Much of this increase in water output appears as water flow during dry seasons when trees would otherwise be depleting water from soil moisture. Thinning or harvesting can be useful if water is needed for agriculture, urban areas (municipal supply), or hydroelectric production.*'

The above narrative is a simplification of what most research scientists believe to be the role of trees in affecting water supply in forested catchments. Smakhtin (2001, p. 151-152) writes:

> Several studies have demonstrated (either by field experiments or by modeling) that afforestation has had a major effect on low flows reducing low-flow volumes to a larger degree than those of annual flow. Deforestation often has a reverse effect on total flow and low flows. It has been demonstrated… that clearfelling and timber harvesting increase annual water yield, and that in many cases this is due to increase in seasonal low flows.

The main assertions of the scientific narrative are that (a) trees in a watershed act to reduce available water; (b) this effect is greatest during dry seasons of low streamflow; (c) deforestation increases the ability of a catchment to produce augmented streamflow; and that (d) reforestation can reduce both total and dry-season streamflow.

Disagreement

Assertions made by the forest-as-sponge narrative about the relationship between forest cover and water yield have come under heavy criticism by the scientific community. Although both narratives share the perspective that forests matter to watershed management, their disagreement on the impacts of forest cover on water availability is irreconcilable. The academic reaction to this disconnect between 'scientific' and 'popular' understandings of the role of forests in local hydrology have been somewhat mixed. Most refer to this forest-as-sponge narrative as a 'myth', though some, such as Kaimowitz (2005), consider it a 'useful myth'. Others, such as Calder (2002), call more forcefully for the 'reconciliation' of these perspectives in favor of a more scientifically accurate perspective.

The importance of the disparity between these narratives becomes clear if we consider their logical prescriptions for managing land to avoid seasonal water shortage, as frequently is the case in the highlands of Central America. The forest-as-sponge narrative, which asserts that forests supply more seasonally continuous water flow, promotes forest preservation and/or reforestation to address seasonal scarcity. The thirsty forest narrative, which regards trees as consumers of water, promotes forest thinning or removal if water supply is the sole objective. For this reason, contention over the forest-as-sponge narrative has crystallized over the subject of payment for ecosystem services.

Ecosystem services are the natural processes performed by ecosystems that benefit human life, such as the filtration of water by soils, production of wood by forests, or the sequestration of carbon by trees. A sub-field of environmental economics works to ascribe monetary value to ecosystem services by the process of valuation. Payment for environmental services by the consumers of those services is a conservation tool that is increasingly being used to preserve valuable ecosystems. The survey previously described by Kosoy et al. (2007), for instance, describes a scenario in which wealthier downstream water consumers pay upland farmers for conservation practices to improve downstream water supply.

Payments for environmental services (PES) related to water management have been growing in Central America (e.g. Kaimowitz, 2005; Kosoy et al., 2007), with some systems receiving World Bank assistance (Pagiola et al., 2005). PES programs have been viewed as a way to simultaneously reduce poverty and increase environmental quality. Many of these schemes are predicated on services performed by forests in headwater areas, including preservation of both water quality and water quantity. When downstream users pay headwater farmers to preserve forested land, or, more problematically, plant new forest *for the purpose of augmented downstream water yield*, then it seems important that this connection between trees and water supply is real. Johnson and Baltodano (2004), in their evaluation of environmental services in the context of community watershed management in Nicaragua, argue that more information is needed on the connection between land use change and forest hydrology. Likewise, Locatelli and Vignola (2009) argue that limited scientific information on the relationship between land use and downstream water quantity presents a serious problem to valuation studies. Kaimowitz (2005, pg. 96), however, provides a slightly different perspective: “To the extent that payment for hydrological services implies a long-term commitment to land uses and agricultural practices that reflect environmental stewardship, it represents a step in the right direction, even if the specific services involved have not been fully demonstrated.”

This brings up a different debate: to what degree does being correct about the impacts of forest cover matter? To help answer this question, I examine the scientific evidence that helps explain, in a more nuanced manner, how trees may be participating in tropical water budgets. I will then explore the forest-as-sponge narrative and how it may have come to be so pervasive. Finally, I will take a look at the work done by each of the narratives and what they may be accomplishing in terms of not only water supply, but also social dynamics and personal behaviors. In doing so, I hope to illuminate a perspective on the debate that goes beyond simple proof or disproof of a particular narrative.

Runoff Generation and Forests

To understand the scientific literature on forest cover and hydrology, it is important to understand a little about how water in a catchment becomes streamflow. All streamflow is derived from precipitation, whether rain, snow, or cloud-interception. Although some precipitation may fall directly into the stream channel, most must make its way through the catchment to reach the stream. The water may travel quickly through the catchment above-ground as surface runoff, more slowly as shallow subsurface flow, or slower still as return flow from the saturated zone (Figure 3.1). Water may be evaporated back into the atmosphere, whether directly from the surface of vegetation (interception followed by evaporation), from water use by plants (transpiration), or from the soil itself. Water may also enter deep aquifers that do not feed water to the stream.

Stream discharge is commonly separated into baseflow and stormflow. Stormflow refers to the portion of streamflow that is immediately responsive to rain events – the runoff that travels via rapid and surface or shallow pathways to the stream channel. Baseflow refers to the water that travels more slowly through the substrate, generally in the saturated zone where it is referred to as groundwater. Streamflow during the dry season is comprised almost entirely of base flow, and is therefore dependent on the amount of water reaching storage in the catchment; the capacity of the catchment to store water; and losses from storage through mechanisms such as evapotranspiration. All of these may be impacted by activities related to land cover change.

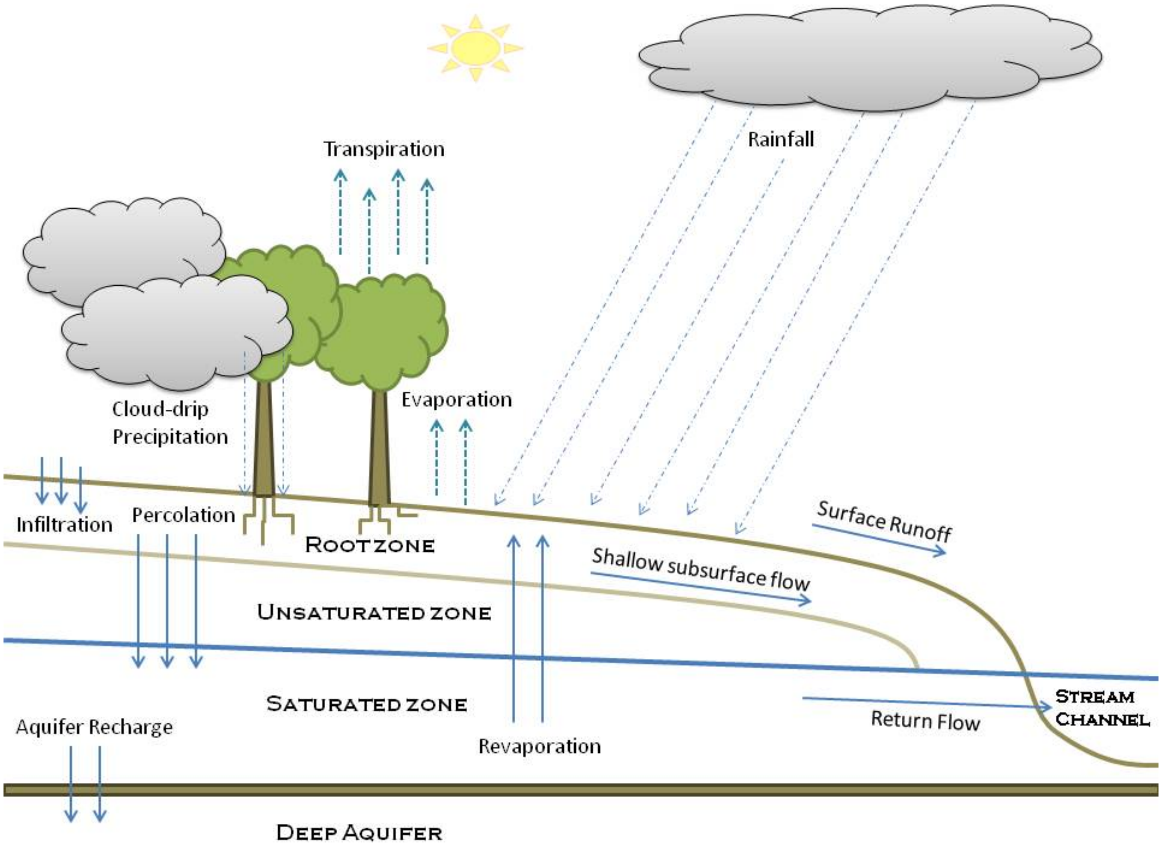


Figure 3.1. Water movement through a catchment.

The first deforestation/water yield experiments in the mid 1900s focused on the possibility of augmenting total annual water yield through forest harvesting. These experiments, mostly involving small, paired catchments in the temperate north, revealed that cutting forests increased overall quantities of streamflow out of the affected catchments and that the amount of increase in water yield was roughly proportional to (but not equal to) the percentage of tree cover removed (Bosch & Hewlett, 1982; Smakhtin, 2001). The reported gains in water yield with deforestation were the result, almost exclusively, of the amount of water used (transpired) by adult trees. Furthermore, it is actually an increase in dry season increase in streamflow that accounts for much of the increase in total annual water yield (Smakhtin, 2001).

The reverse is also true; reforestation results in decreased water yield (e.g. Borg et al., 1988; Pearce, et al., 1987; Trimble et al., 1987). Developing forests have high rates of transpiration, often producing higher water demand than the original mature forest. Reforestation thus may produce a decrease in streamflow beyond initial forested conditions (Bruijnzeel, 2004; Smith & Scott, 1992). Smith and Scott (1992) demonstrate in an experiment in South Africa that the type of tree is highly significant to the magnitude of the reduction. However, responses to land cover change are highly variable and significant results disappear with increasing catchment size (Bosch & Hewlett, 1982).

Tropical forests may exhibit a different hydrologic response to changes in forest cover than temperate forests (Hamilton & King, 1983). Results of some paired watershed experiments conducted in the humid tropics have produced similar results to the bulk of literature on forest removal – increased total streamflow and increased base flows. But relatively few controlled studies have been performed in the tropics, and the results of the individual studies have been less conclusive than those performed elsewhere (Bruijnzeel, 2004). Meta analysis of this problem by Locatelli and Vignola (2009) suggests again that the type of forest is important. Planted forests had significantly lower total water yields and baseflow than non-forested land uses. There was no significant difference between natural forests and non-forested land uses overall, but small watersheds showed less total flow under natural forest while large watersheds showed more baseflow under natural forest than under non-forested uses. The researchers caution, however, that the small number of studies available on land use and tropical hydrology limits the strength of the conclusions presented (the authors were able to locate only 20 usable studies, only one of which was from the Latin American region).

The impact of forest cover on dry season streamflow becomes more complex when we consider soil degradation from forest-clearing activities. In experimental conditions, forest removal does not greatly impact soil infiltration capacity. In contrast, forest removal in a non-experimental setting often causes significant soil degradation. In Central America, forest harvesting is often synonymous with landscape conversion. Cut forests are often burned and used for either agriculture or pasture. Both burning and grazing, particularly on steeper slopes, are associated with degradation of soil structure and reduction of infiltration and storage capacity (Smakhtin, 2001). Reduced infiltration decreases the amount of water reaching storage in the catchment, while soil loss from erosion and soil compaction related to vegetation removal and poor management may decrease the overall capacity of the catchment to store water (Smakhtin, 2001). Although largely unsupported by rigorous experimental data, many narrative accounts exist correlating forest removal with both lower flows in the rainy season and higher flows in the dry season (Ataroff & Rada, 2000; Bruijnzeel, 2004).

Finally, a large number of high, forested catchments are within zones of montane cloud forest, where water inputs from cloud condensation on leaves and trunks are significant (e.g.Gonzalez, 2000). These forests may represent an exception to the rule of increasing water yields with forest removal, even in experimental settings where changes in infiltration capacity are minimal (Bruijnzeel, 2004). Montane cloud forests are located in the mountainous highlands and account for about 12% of tropical Central American forest cover (Mulligan & Burke, 2005). Because these regions receive a significant percentage of their total water in the form of cloud interception, the catchment is actually losing an input to the water budget when forests are cut. Whether or not water yields are increased with deforestation depends on the balance between decreased losses via transpiration and decreased inputs via interception (Bruijnzeel, 2004).

In a modeling exercise, Mulligan & Burke (2005) calculated that the mountains of Costa Rica generally receive between 50 and 150 mm/yr of additional water through cloud-drip, while some areas may receive as much as 250-400 mm/yr. Although precipitation inputs from cloud-drip generally represent a small proportion of the total annual water budget (< 2% in the wettest areas), in isolated zones fog inputs were occasionally greater than 20% of the total budget. The authors demonstrated that seasonality is highly important – some catchments receive a low percentage of their total streamflow from cloud-drip during wet months, but nearly all of their streamflow from cloud-drip precipitation during dry months. However, only in the most exceptional cases was streamflow shown to decrease with forest removal in the modeled results.

An experiment by Ataroff and Rada (2000) comparing water budgets in virgin forest and converted pasture in a cloud forest in Venezuela indicated that conversion to pasture was likely to significantly decrease dry season flow in these forest types. Conversion of lowland forests to pasture upwind of these cloud forests may also impact dry season flows by increasing the altitude of the dry season cloud base (Nair et al., 2003; Ray et al., 2006).

The results of these experiments demonstrate that in regions receiving high levels of precipitation by cloud-interception, protection of forests and reforestation may actually have the results anticipated by the forest-as-sponge narrative, though the mechanisms by which dry-season streamflow is increased are not fully accurate. Cloud-drip precipitation is not conventionally considered in hydrologic models or calculations of water budgets, making conventional scientific analysis of the water budgets of these regions problematic. The general conclusion of these studies, however, is that cloud-drip-dependent systems are highly localized and only relevant at small spatial scales. In the big picture of Central American forest management, the water gains from decreased forest cover are generally believed to far exceed the losses in these small areas (Bruijnzeel, 2004; Mulligan & Burke, 2005).

The forest-as-sponge narrative comments on the impacts of forest cover on both seasonal low flows and flood flows. In the narrative, forests decrease the severity of floods by allowing for increased storage of floodwater in the soil. While this may be accurate at small spatial scales, a reduction in flooding has not been demonstrated at larger scales, such as the regional and national scales discussed in reference to the impacts of Hurricane Mitch (e.g. Bruijnzeel, 2004; Kaimowitz, 2005). For the purpose of this investigation, however, I will be focusing on the impact of forest cover on seasonal low flows.

Origins of the Narrative

The concept of environmental imaginaries provides a useful perspective on the way people understand the environment. Environmental imaginaries can be defined as “place-specific social hierarchies of environmental discourses that provide the languages, norms, metaphors and meanings for constructing and expressing nature” (McGregor 2004, p 595). The concept of environmental imaginaries emphasizes the role of institutions and social structures in creating and propagating ways of viewing the natural world and de-emphasizes the role of individual agents. In the case of Central American water management, environmental imaginaries are created and propagated both through governmental and non-governmental organizations by way of national policy initiatives, Inter-American Development Bank (IDB) programs, and outreach initiatives by charitable organizations such as Catholic Relief Services. Many of the people participating in the narrative of the sponge are simply buying into a shared environmental imaginary that helps explain the purpose and function of the natural world.

The forest-as-sponge narrative is not limited to Central America, but is found throughout the tropics in what is conventionally considered the developing world. For instance, a study by Wilk (2000) conducted in Thailand and India using semi-structured interviews revealed a consistent perception that forests increase water availability over other land uses due to their ability to retain water. The narrative has become part of a simplified global discourse that has been widely incorporated into the management of watersheds.

I argue that it is a combination of socio-political factors including environmental pushback over development policies in USAID and the World Bank, the proliferation of NGOs and the mushrooming of international aid, and the social construction of environmental crises in Central America that created the structures through which the narrative was easily propagated. The development and dissemination of the idea of Integrated Water Resources Management (IWRM) throughout global policy networks such as the World Bank created an internationally recognized policy framework that emphasized the interconnectedness of forests and watersheds. Forests were frequently cited as playing a role in regulating catchment hydrology, and at times the narrative of the sponge was directly invoked (e.g. Johnson & Cabarle, 1993; Leonard, 1987). Meanwhile, the invention of environmental catastrophes such as the premature closure of major dam projects in Central America created demand for integrated environmental solutions

(Kaimowitz, 2005), allowing these new development policies to be readily incorporated into the Central American policy framework.

As outlined in Chapter II, critics began to strongly question the policies of multilateral organizations such as the World Bank and USAID in the late 1980s after a decade of increased aid to Central America with no clear benefits (e.g. Danaher et al., 1987; Karliner, 1989; Sollis, 1992). Meanwhile, the World Bank was coming under heavy criticism for failure to address the social and environmental costs of many of its large-scale development projects. This push-back against the status quo in development aid created the momentum for policy reform within the agencies that would address concepts of equity and sustainability. IWRM, with its vague, idealistic language, provided the structure for reform in the water sector.

IWRM, at least as a labeled concept, made its international debut around 1992 with both the Dublin Conference on Water and the Environment and the United Nations Rio Summit on Environment and Development (Jeffrey & Gearey, 2006). The Dublin Principles outline preferred methods for managing water resources in both small and large watersheds worldwide. One of the three principles outlined, the Ecological Principle, argues that water management should be focused at the scale of the river basin and that land, water, and environmental management should occur together rather than under the direction of separate entities (The World Bank, 2004). This integration of forest, land, and water management in now regarded as a 'best practice' internationally for the management of water resources.

The idea of integrated management of river basins has become central to the way that many aid agencies and the governments of developing countries view water resources (Barrow, 1998). IWRM has now been adopted by such programs as the United Nations Development Programme, the United Nations Environmental Programme, the World Bank, the Asian Development Bank, the World Water Council, the European Union Framework Directive, and the Global Water Partnership (Mukhtarov, 2008). These organizations are highly influential in the global arena, in no small part because they control the purse strings to large-scale development projects. They also create and disseminate goals and frameworks that become the *de facto* standards of the industry and are emulated by smaller NGOs. World Bank involvement in watershed management activities at varying scales has rapidly increased over the past decade or so. Development organizations have begun adopting the language of IWRM in their project statements, regardless of its functionality in guiding the project. Mukhtarov (2008) has argued that IWRM owes it ubiquity in modern methodological frameworks not to its usefulness or effectiveness, but to the fact that it has been adopted and promoted by major policy-making bodies such as the Global Water Partnership.

IWRM has many recognized problems. Barrow (1998), in a review of river basin development planning and management, argues that in many cases lack of baseline data, lack of monitoring, and false assumptions present major obstructions to success. Even the idea of managing water at the scale of a watershed is problematic. Watersheds are sets of nested and surprisingly fuzzy boundaries whose physical definition is influenced by scale, geology, and human distortion (e.g. via municipal water systems or irrigation diversions). Because of this, watershed definition in itself is a distinctly political act (Blomquist & Schlager, 2005). Deciding who and what it included in watershed management plans is not an objective task. Under IWRM, planners and managers of water resources try to think holistically about watersheds, but often lack the information, technology, and objectivity necessary to think critically and accurately about how the watershed is actually functioning.

Couched in the language of IWRM, the narrative of the sponge appears in many of the documents and policies of development organizations such as the IDB and the World Bank, and well as in the project statements and goals of the myriad of small-scales NGOs who derive their standards from these larger organizations. An example comes from a regional profile report on natural resources in Central America created by USAID (Leonard, 1987, p. 10):

> Many steep and rugged watersheds have been cleared by fire, by extension of agriculture and grazing and by other careless land use practices. This has caused massive erosion, increasing flooding and mudslides during the rainy season, and has contributed to reduced stream flows during drier times of the year.

Here the forest-as-sponge narrative is explicit – clearing of the watersheds results in increased flooding and decreased dry season flows. The document goes on to promote upland watershed management for all water supply projects, a policy which was carried out by way of multiple large-scale reforestation programs throughout Central America.

In other documents, promotion of IWRM simply included language about the importance of forests to catchment hydrology. A Water Resources Sector Strategy document from the World Bank (2004, p. 20) outlines "strategic directions for World Bank engagement" and identifies management of forests as "essential for *moderating hydrological variability*, reducing silt and conserving biodiversity." Broad statements such as this have likely helped perpetuate the idea that forests are a panacea for water-related problems including the magnitude and timing of both high and low flows in a watershed.

Personal experience working with international NGOs in Central America revealed that employees of these NGOs, including executive-level administrators, actively participated in the telling of the forest-as-sponge narrative. Moreover, this narrative was used explicitly as an example of the importance of IWRM to the projects they were undertaking.

The history of Central America from the 1970s through the 1990s created fertile ground for importation of IWRM. The massive damages associated with Hurricane Mitch (which struck Central American in 1998) are frequently used as proof of the environmental services performed by forests and as justification for large-scale investments in watershed management programs (Kaimowitz 2005). Kammerbauer et al. (2001, p. 59) state:

> It is hoped that some lessons can be learned from the present micro-scale case study, and also from the well-known catastrophic hurricane event which took place in 1998 in Honduras, both showing the strong connectivity on the environmental systems and their functions and services among regions.

Additionally, scientific reports through the 1970s and 1980s warned of massive sedimentation and potential failure in high profile dams such as El Cajón as well as the Panama Canal (Kaimowitz 2005).

Although these reports turned out to be, for the most part, false or overblown, the idea that forests were critical to the region's hydro-electric production, both to provide adequate flow and reduce sedimentation rates, stuck. A 1983 article printed in Ambio cites massive deforestation as the reason ‘a major dam’ may close after only 30 years due to excessive siltation, and blames soil loss from deforestation for massive changes in hydrologic regimes (Salati & Vose, 1983). The quote from the beginning of this chapter from the Water Resource Institute (which was used as an example of the forest-as-sponge narrative) blames the risk of decreased hydro-electric production on tropical deforestation. Comprehensive watershed management became something of a patriotic duty to protect the region’s hydro-electric capacity. As a result, the establishment or protection of forests became a basic rule-of-thumb in managing water crisis.

Within this structure, the narrative of the sponge became a way to appeal to upland farmers who might not otherwise have a stake in reforestation. According to Kaimowitz (2005, pg. 88):

> Many NGOs wished to convince local farmers and communities that environmental problems affected their well-being directly and used catchment degradation as a case in point. These groups told farmers that if they cleared additional forest and failed to protect their soils, their water sources would dry up, their yields would decline and their crops would receive less rain.

Of all the so-called environmental ‘myths’ surrounding resource management in the region, the connection between seasonal low flows (and therefore seasonal water scarcity) and forest cover provides the most convincing justification to involve upland farmers in larger reforestation initiatives for the benefit of the farmers themselves.

The Narrative at Work

To only examine the factual validity of the narrative is to miss much of its substance. The narrative of the sponge is accomplishing real work in Central America, some of which is useful and some of which is counterproductive or damaging. In order to truly assess the merits and flaws of the narrative of the sponge, it is important to take a closer look at how the narrative is functioning – what it supports, promotes, defends, and denies. The narrative supports the idea of IWRM and tropical forest conservation, bolsters payment for environmental service (PES) schemes (see page 15 for definition), and justifies the importance of intact forests, both at intensive and extensive spatial scales.

The forest-as-sponge narrative reinforces the connection between land and water management. In the narrative, trees protect the capacity of the catchment to store and deliver water throughout the year, making management of forests critical to management of water. This connection supports a basic premise of the Integrated Water Resources Management paradigm – that water management requires the participation and coordination of multiple sectors (in this case forestry and hydrology). The narrative helps legitimize the promotion of IWRM by global institutions such as the Global Water Partnership as well as its adoption by national and local governments and by regional and local NGOs.

Through the same logic, the forest-as-sponge narrative supports the cause of tropical forest conservation and allies the tropical forest conservation movement with water management. The destruction of tropical forests became a high profile issue of international concern, with numerous authors expounding the dangers of tropical forest loss for planetary health and biodiversity (e.g. Karliner, 1989; Salati & Vose, 1983). For those concerned about tropical forest loss, the forest-as-sponge narrative reinforces justification for preservation and reforestation at multiple scales.

At more extensive spatial scales, the narrative capitalizes on concerns over hydro-electric potential by arguing that forests help ensure both the quality and continuity of water supply. At this scale, the myths inherent in the narrative seem relatively benign. The narrative is working to preserve an important resource, regardless of its actual importance to the region's hydro-electric facilities.

At smaller scales, the narrative provides powerful justification for the importance of intact forests to individual settlements in even the most remote areas. It works to convince individuals that preservation and reforestation are beneficial or even critical to their well-being. However, these forests may actually be reducing available water. The narrative's work in this regard is potentially more damaging, even though it is mostly well-intentioned. Though forests are useful for a variety of reasons, placing excess burden on already water-scarce communities in the name of forest conservation seems unfair at best and purposefully manipulative at worst.

The implementation of PES schemes (see pg. 15) also benefits from the forest-as-sponge narrative. The production of water by forests, particularly during scarcity, creates a product that downstream users can buy from the upstream producers. Unlike services performed by forests such as the preservation of biodiversity or purification of air, production of streamflow establishes a direct causal relationship between the actions of different groups of people (i.e. those preserving forests higher in the watershed and those using water lower in the watershed). Although there is a very well established relationship between forest cover and water quality, downstream users seem less willing to pay for incremental increases in water quality than water quantity (Kosoy et al., 2007). Because water yield is such a valuable resource, this justification convincingly establishes the framework for PES, regardless of the fact that logic binding the scheme together is erroneous.

Some of the work accomplished by the narrative is accomplished solely through its simplicity. In the international discourse surrounding development, the conventional wisdoms about how development should take place often become cemented into development narratives – hardy and relatively simple stories that facilitate decision-making (Roe, 1991). The forest-as-sponge narrative can be viewed as a perfect example of a development narrative. Development narratives are conveyed through legislation, policy documents, and development initiatives. Roe (1991) posits that development narratives are a response to uncertainty. They simplify processes too complex to easily navigate and provide simplified blueprints for decision-making. The relationship between forest cover and streamflow in the humid, tropical regions of Central America is too complex to facilitate easy decision-making in water policy. Cyclical climatic variations caused by el Niño/la Niña weather patterns, along with the general stochasticity of weather events, makes casual observation of cause and effect processes in land cover change and hydrology virtually impossible.

In spite of its flaws, the forest-as-sponge narrative does capture important truths about water management. In this way, the narrative is partially justifiable as an educational tool. The forest floor (sans pump-like trees) has the sponge-like qualities described in the narrative, though a soil-as-sponge narrative would be more appropriate.

Additionally, it is possible to imagine forest conversion scenarios so extreme that the degradation of soil reduces storage and subsequent runoff to a greater extent than decreased evapotranspiration increases runoff. At the very least, the forest-as-sponge narrative instructs people that streams are connected to their watersheds, and that changes in land cover can result in changes to the water in the streams.

Kill the Beast?

Given that the narrative-of-the-sponge is, in most cases, false, many scientists and policy-makers have actively spoken out against the myth, calling it an impediment to progress on management issues. Others, such as Kaimowitz (2005), point out that although false, the narrative has some merit in its proven ability to focus attention on forest preservation and water management issues. There seems to be little consensus on what to do with the narrative – whether to embrace it, improve it, or discard it – and how to go about doing so.

Although it may be tempting to simply debunk the forest-as-sponge narrative and move on, the likelihood of exterminating the narrative from the public consciousness may be very low. Development narratives as described by Roe (1991) have historically been resistant to scientific evidence refuting them. The forest-as-sponge narrative has already persisted in development initiatives for many years in spite of the common scientific understanding that it is false (e.g. Calder, 2002; Bruijnzeel, 2004; Kosoy et al., 2007).

In many ways, the battle over the forest-as-sponge narrative resembles a longstanding argument in the geomorphology community over the Rosgen river classification system that is commonly used in river restoration. For the most part, there is a consensus among scientists that the classification system is seriously flawed and should not be used. But the multi-billion-dollar river restoration industry still uses it as a gold standard in the design of restoration projects, probably because it is the only simple and prescriptive solution to have been posed (Lave, 2012). And much as the scientific community balks, they have been almost completely unsuccessful in convincing the restoration industry to move away from the system.

The forest-as-sponge narrative, like the Rosgen classification system, is simple and prescriptive. It is also factually inaccurate. But the big businesses (non-profit or otherwise) that specialize in watershed management in the developing world are more likely to base their work on easy heuristics than complex contingencies that require tremendous time, effort, and money to resolve. It is difficult to determine the precise impact a land cover change will have on water supply in a catchment. The beauty of the forest-as-sponge narrative is that the prescription is always the same – the more trees, the better.

The narrative of the sponge has both merits and flaws. It emphasizes the protection and restoration of forests throughout Central America, albeit through tenuous logic. But if the end result is the preservation for forests, does this really matter? The answer is not entirely clear. The overall preservation of forest cover is a benefit – for biodiversity, for firewood, for water quality, and perhaps even to mitigate the hazard of shallow-mantled landslides (May, 2002; Montgomery et al., 2000). But if we consider the scale of an individual, rural catchment where residents depend directly on streamflow for their water supply, the narrative loses some of its appeal. The forest-as-sponge narrative has been used to justify large-scale reforestation projects in the watersheds of large dams and important lakes (including those in the Panama Canal). These frequently use non-native species and focus reforestation in highland areas that see no economic benefit from the dams or lakes (Calder, 2002; Kaimowitz, 2005). The newly planted forests, especially when young, may have water demands that significantly decrease local water supplies in small, headwater catchments. If the people who rely on these water supplies receive no other substantial benefit from the reforestation efforts, then the use of the narrative could be seen as coercive and damaging. Is the whole-sale recommendation of reforestation advisable in these situations? Or should it come with caveats?

To help answer these questions, the next chapter will focus on the value of the forest-as-sponge narrative to a specific micro-catchment in Central America – the Rio Sasle catchment in Nicaragua. Using the SWAT hydrologic model, I will explore the impacts of a series of land cover change scenarios on the magnitude and timing of flows in the Sasle basin. Understanding the potential results of land cover change at this scale will help bring into focus how the forest-as-sponge narrative might be interacting with catchments, people, and livelihoods.

CHAPTER IV

CASE STUDY – RIO SASLE, NICARAGUA

Introduction

To better understand the impacts of changes in forest cover in Central American catchments, I focus on a case study and modeling experiment in the Rio Sasle watershed in Nicaragua (Figure 2.1). The Sasle Catchment, described in Chapter II, is a small, rural, highland catchment in Nicaragua. Land use in the catchment is a typical mix of coffee plantations, cattle ranching, and a patchwork of small-scale agriculture and forest land. Farmers living within the catchment suffer from seasonal water scarcity, and the NGO working in the community is looking to address this scarcity through a mix of infrastructure development and possible reforestation. Given that scientific studies indicate that reforestation is likely to reduce dry season streamflow, this case study addresses the conflict between these narratives as they are playing out in a particular place and what they may mean for water availability at the community scale.

This focus on a small, upland catchment like Sasle is appropriate because watersheds of this scale are sensitive to the hydrologic impacts of land cover change (Nelson & Chomitz, 2004). Upland areas tend to contain a patchwork of forested and agricultural land, creating the potential for a higher percentage of the watershed to experience land conversion through reforestation or clearing. There is also a more direct relationship between water yield and forest cover in small watersheds (on the order of tens of km^2 or less) that begins to disappear with increasing catchment size (Bruijnzeel, 2004; Nelson & Chomitz, 2004). It is at these small scales that many NGOs are focusing their efforts in watershed management, making this scale of study important for analysis.

To characterize effects of changes in land cover on runoff, I use supervised image classification of Landsat satellite imagery to document land cover in the Sasle catchment over the past 25 years. Using the Soil and Water Assessment Tool (SWAT), I model the impacts of land cover changes on runoff in the Sasle catchment.

Methods

Image Analysis

Before modeling the impacts of land cover change in the Sasle catchment, I assessed actual land cover change in the catchment over the last 25 years. I chose to use Landsat satellite imagery to perform this analysis because it is free and has sufficient temporal resolution to acquire cloud-free images, which is a difficult task in the tropics. Additionally, my methodology is easily replicable by small agencies and organizations with limited funding. Landsat's spatial (30 m) and spectral (seven bands) resolutions restricted the number of mappable land cover categories, but was sufficient for indentifying change in forest cover over time.

I selected one image each from 1986 and 2011 for the classification. The images had little cloud cover and good image quality (as specified by the Landsat program). They were taken in January and February, which minimized the impact of seasonal differences in vegetation cover, sun angle, and shadows on classification.

In order to compare images across time, I applied atmospheric and radiometric correction to all the images using the COST model as adapted by the ARSC (Chavez, Jr., 1996; Arizona Remote Sensing Center, 2002). COST is an image-based method of atmospheric correction that uses solar zenith angles to approximate atmospheric transmittance, with results that are as accurate as methods using in-situ atmospheric field measurements (Chavez, Jr., 1996). This processes converted the Landsat TM5 digital counts to ground reflectance, allowing for more accurate classification and comparison of images.

I classified land cover in the two images using a supervised classification approach in ERDAS Imagine software. I classified each image multiple times using different sets of training pixels, creating a range of land cover maps for each year. I mapped four land cover categories: forest, pasture, garden plots, and bare ground. These categories, based on trial classifications, were spectrally unique and created a meaningful (if simplified) model of the watershed. Although bare ground and garden plots were spectrally dissimilar, they represent alternative phases of the same basic land use and were later combined into a single land class for analysis. Clouds and shadow, though minimal in the images, were classified and then eliminated from the analysis. The 'forest' classification included natural forest and coffee plantations.

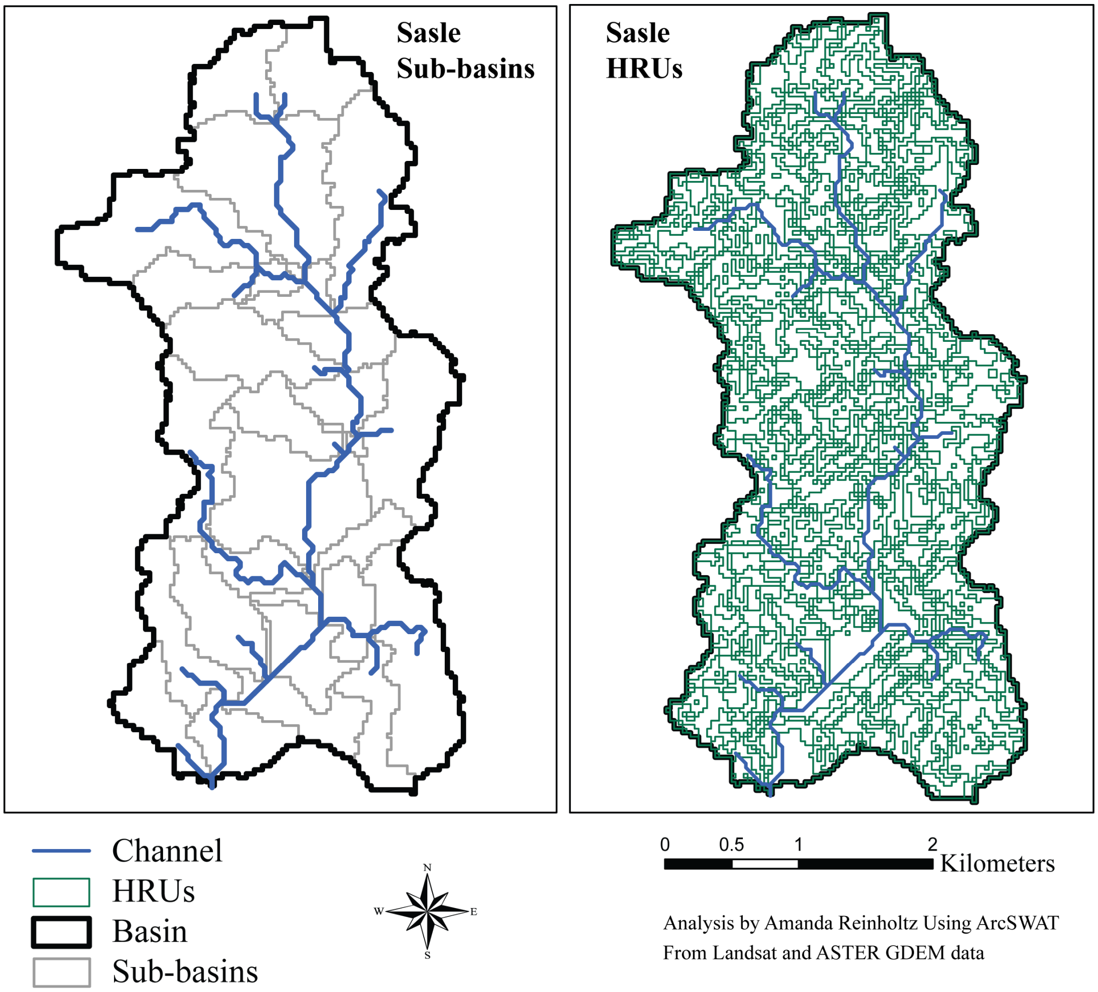
Classification of the 2011 image was verified qualitatively using higher spatial resolution Google imagery, a map of the watershed created using a community mapping exercise, and field notes and sketches of the watershed. This method of land classification is not very precise, but absolute accuracy was not a critical goal. The purpose of the exercise was to create a general characterization of the watershed at two points in time from which I could simulate runoff for realistic watershed conditions. Error matrices are therefore unnecessary.

SWAT Model

In selecting a runoff generation model, I was constrained by both modeling objectives and data limitations (for instance, the absence of gauged stream data). The project required a physically-based model with minimal data requirements capable of modeling flow over multi-year periods. SWAT, the Soil and Water Assessment Tool, offered the necessary analytic capabilities.

SWAT is a physically-based, catchment-scale hydrologic model originally designed by Jeff Arnold to assess the impacts of management practices on water, chemical, and sediment yields (Neitsh et al., 2011). In SWAT, the watershed is divided into sub-basins (Salse sub-basins are shown in Figure 4.1). Sub-basins are, in turn, divided into the stream channel (the reach), groundwater, climate, and Hydrologic Response Units (HRUs). HRUs are lumped land areas with unique soil, land cover, and slope combinations. Dividing the land surface into HRUs allows each to have unique evapotranspiration and runoff responses according to their respective properties. The model uses a water balance approach, tracking masses of water from one stage or storage to another. Fluxes for each component are based on published physically-based and/or empirically-based hydrological rules.

SWAT uses climatic inputs (minimum/maximum temperature, rainfall, solar radiation, windspeed, and relative humidity) on daily timesteps.



Analysis by Amanda Reinholtz Using ArcSWAT
From Landsat and ASTER GDEM data

Figure 4.1. Delineation of sub-basins and HRUs in SWAT

Climate Data

No climate stations exist in the Sasle watershed. In absence of Salse gauging data, I interpolated climate conditions to create a representative climate year. I repeated this data three times consecutively to create a three-year modeling period to input to SWAT. This allowed two years for the catchment to reach equilibrium before entering into year three. Only the final year of modeling is included in the results.

I acquired monthly average precipitation and minimum/maximum temperature values for the Sasle watershed from the WorldClim dataset. WorldClim is a relatively high resolution (1km) dataset of interpolated climate surfaces derived from a global network of climate databases, SRTM elevation data, and ANUSPLIN interpolation software averaged over the period of record to represent average climate conditions for 1960-1990 period (or 1950-2000 in data sparse areas). In the WorldClim dataset, each climate variable for each month (e.g. precipitation for January, precipitation for February, etc.) is represented by a unique raster dataset. SWAT requires climate data with discrete point measurements rather than spatial distributions, so I projected each of the relevant datasets onto the Sasle catchment and calculated the average value of all cells at least 70% within the catchment (defined to exclude cells that only slightly overlapped the catchment area) for each month for each variable.

The SWAT model requires a daily timestep for climate data, and the WorldClim dataset only offers monthly average values. To resolve this, I performed a temporal downscaling of the WorldClim climate data. For temperature data, daily fluctuations around the monthly mean were not important to my modeling question. To create the daily data, I assigned the average monthly value to the 15th of each month and used a linear interpolation between these values, resulting in a smooth daily transition between monthly averages.

The same method would not suffice for downscaling of the precipitation data because precipitation occurs in discrete events and varies widely on a daily basis, and because these discrete events are important to the hydrologic response of the catchment. Instead, I substituted precipitation records from the nearby city of San Rafael del Norte, Nicaragua. The records are from the NCAR Earth Observing Laboratory data records. Although this station is geographically close (less than 10km from the Sasle catchment), topographic effects result in a significant difference between annual rainfall averages for the two locations (as estimated by the WorldClim dataset). Still, because the data was derived from a weather station recording actual daily data, this dataset was better suited to modeling a ‘realistic’ rainfall pattern in the catchment.

Other Input Data

I used ASTER GDEM data at a 30m resolution as the topographic baselayer for the watershed. There is likely some distortion to the catchment both from the resolution of the data and the influence of vegetation on elevation data. These distortions are not particularly worrisome because the goal of the modeling exercise is not to predict actual future streamflow in the catchment, but to model differences in streamflow within the same physical catchment under different land cover conditions.

The entire catchment fell within a single soil type in the FAO soil database (soil Bd26-2bc). Because all the hydrologic properties of the soil necessary for the SWAT model were not known, I used the pre-existing attribute values for the most similar soil type in the pre-existing SWAT soils database.

All SWAT data inputs are summarized in Table 4.1.

Table 4.1. Summary of SWAT input data

Subject	*Source*	*Year*	*Type*	*Resolution*
Elevation	ASTER GDEM	2009	raster	30m
Min/Max Temp	WorldClim	20-yr average	raster	1km
Precipitation	NCAR Earth Observing Lab	1986	point	one station
Land Cover	LANDSAT TM	1985, 2011	raster	30m
Soils	FAO/UNESCO	2003	vector	1:5000000

Running SWAT

I ran the SWAT model for a range of land cover scenarios, using identical climate data with each run. Land cover scenarios included the actual classified land cover data from the remote sensing exercise, as well as three ‘extreme’ conditions in which the entire catchment is comprised of a single land cover classes (forest, pasture, and agriculture).

Results/Discussion

Image Classification

Results of the image classification exercise are summarized in Table 4.2, Figure 4.2, and Figure 4.3. The summaries include the results of three unique classifications for each image to represent the range of results from my analysis and to compensate for the absence of quantitative validation. Forested land cover in the watershed decreased during the period between 1985 and 2011 from 29-32% to 17-25%. Agricultural land increased by a similar margin from 40-48% to 51-58%. There was no significant change in pasture.

Table 4.2. Results of land cover classification. Percentages may not total to 100% due to rounding and the exclusion of cloud cover and shadow from results. Scenario 1 represents the lowest estimate of forest cover using supervised classification, Scenario 3 the highest estimate of forest cover, and Scenario 2 is an intermediate classification.

% Cover				
Year	**Scenario**	**Forest**	**Pasture**	**Garden/Bare**
2011	1	17	24	58
	2	22	26	51
	3	25	16	58
1985	1	29	20	43
	2	30	22	48
	3	32	22	40

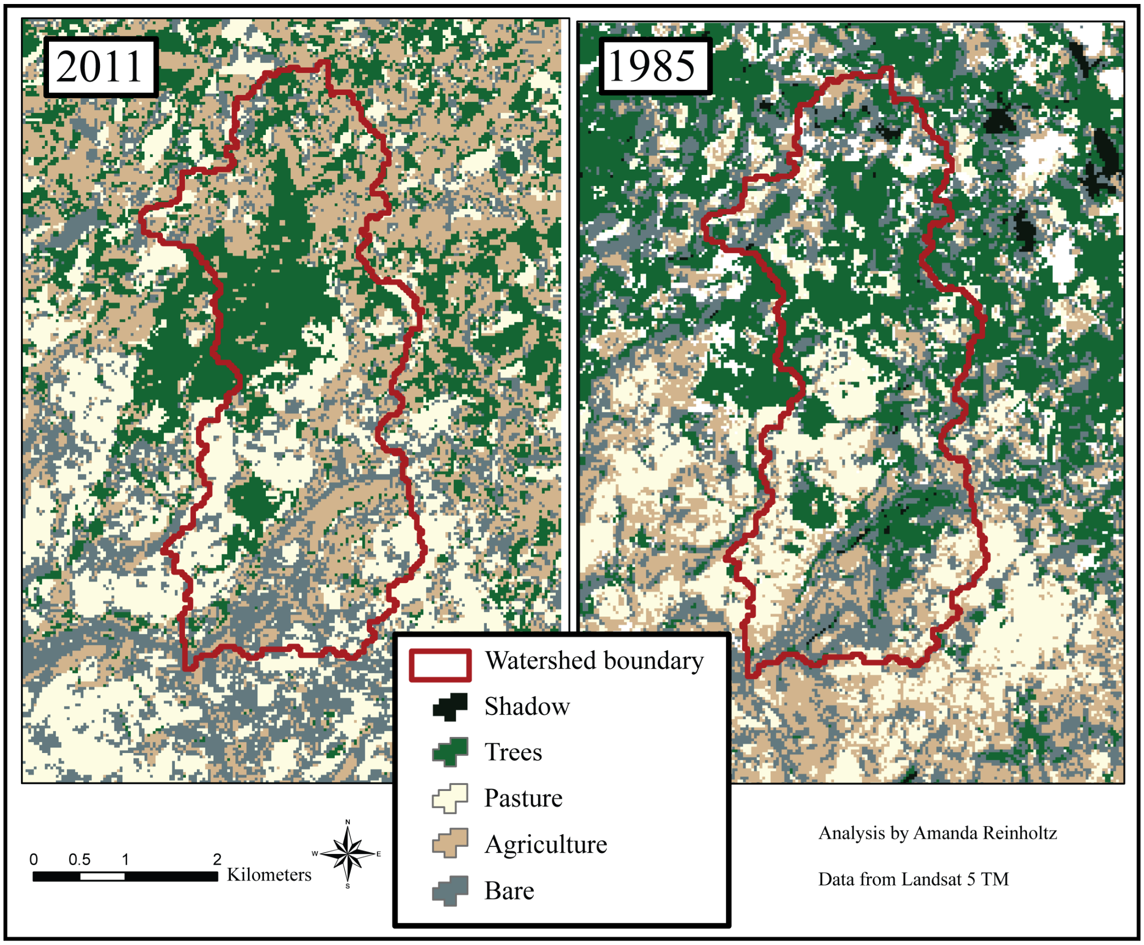


Figure 4.2. A set of image classification results for 1985 and 2011 (Scenario 2).

Results also show a shift from dispersed forested land throughout the upper catchment to a consolidation of forest in a couple of major patches. From ground-based observations, I know the larger of these patches to be a cluster of coffee plantations while the smaller clusters represent natural or regenerating forest. Although results indicate that the total rates of deforestation have been fairly low, the conversion of agricultural land to coffee plantation forest is obscuring higher rates of land conversion from native forest to agriculture.

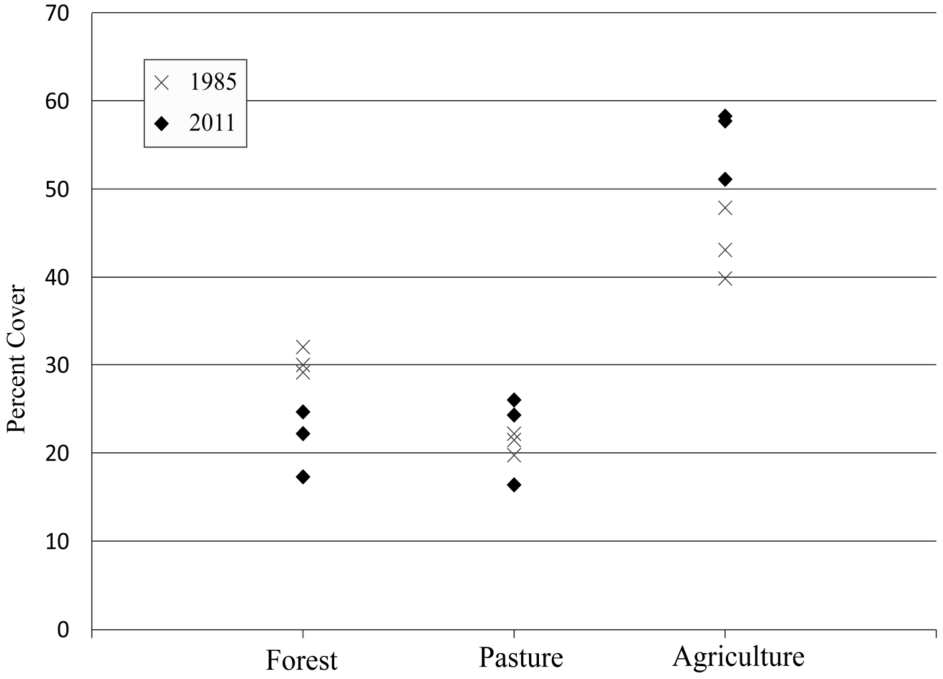


Figure 4.3. Comparison of percent land cover between categories. The three data points for each date and cover type represent results from Scenarios 1, 2 and 3 (see text for explanation).

SWAT Model

To characterize the hydrologic response of the Sasle catchment to changes in land cover, I used three scenarios in which the catchment had a single land cover category – forest, agriculture, and pasture. I also modeled mixed land cover scenarios based on the 1985 and 2011 land cover classifications.

The model results show rates of evapotranspiration were greater for pasture and agricultural uses for most of the year, but evapotranspiration was highest under forested land cover during the dry season. Accordingly, soil water volume in the catchment was greatest under forested conditions for the majority of the year, but lowest for forested conditions during the dry season due to its high water use year-round and its superior ability to access limited soil water. Soil water and evapotranspiration results are shown in Figure 4.4.

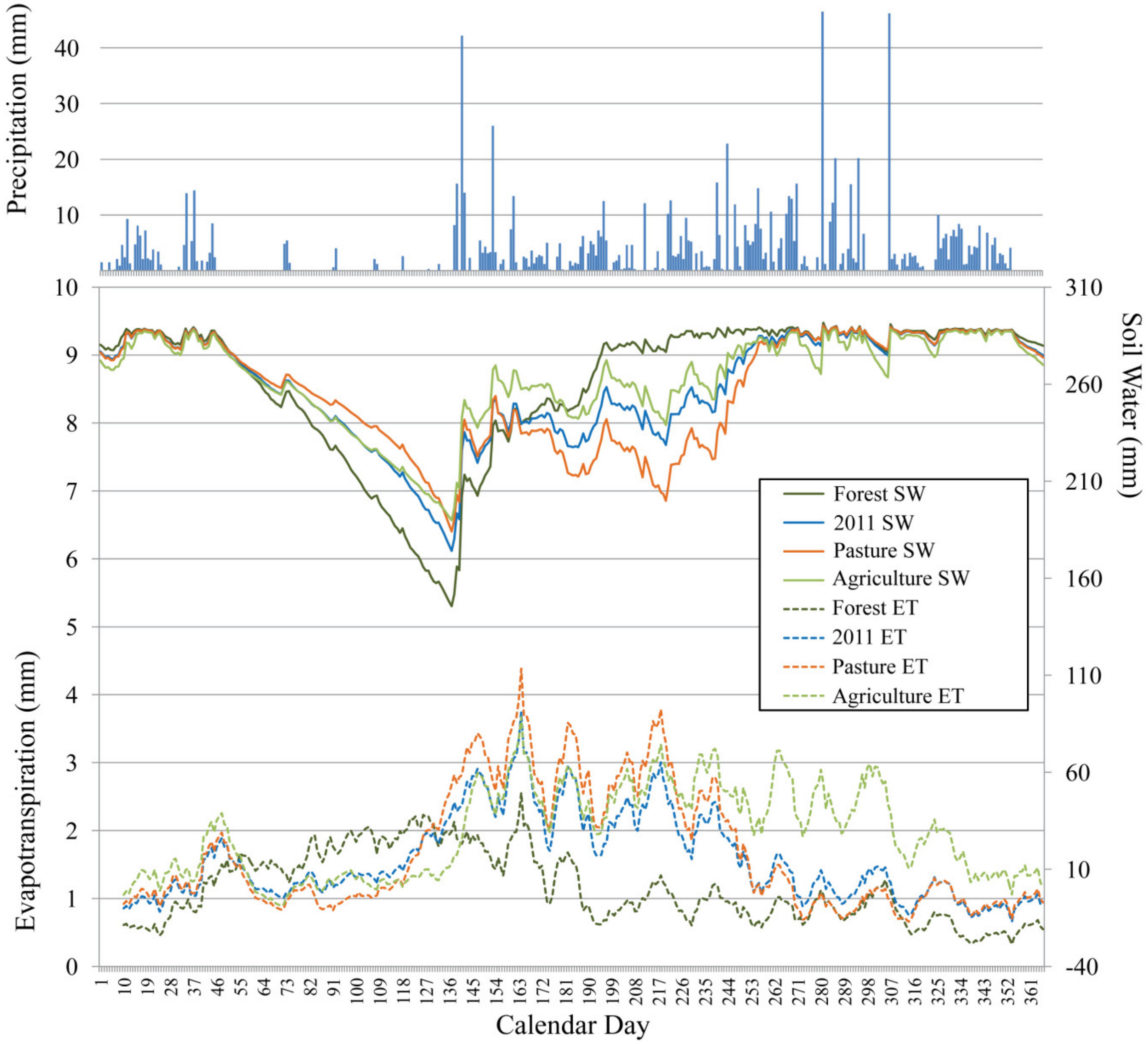


Figure 4.4. Results of modeling in soil water (SW) and evapotranspiration (ET) for four land categories where the watershed is 100% forest, 100% pasture, 100% agriculture, and actual 2011 land use (Scenario 2). Precipitation is shown above for reference.

SWAT results consistently show water yield being highest for forested land cover and lowest for purely pasture land cover during the wetter parts of the year. Water yield results were inconsistent for the dry season in the lowest flows. The results below, where water yield under forested conditions is lower than that of other land uses, seem most consistent with results from evapotranspiration and soil water (Figure 4.5). However, the model also produced results in which water yield for forest land cover was always greater than that of all other uses. Water yields during this portion of the year are very low (near zero), and the absolute difference between any two land cover types during this part of the year is accordingly small. It is possible that the modeling scenario presented, where quantities of water were exceptionally small, surpassed the precision limits of the model.

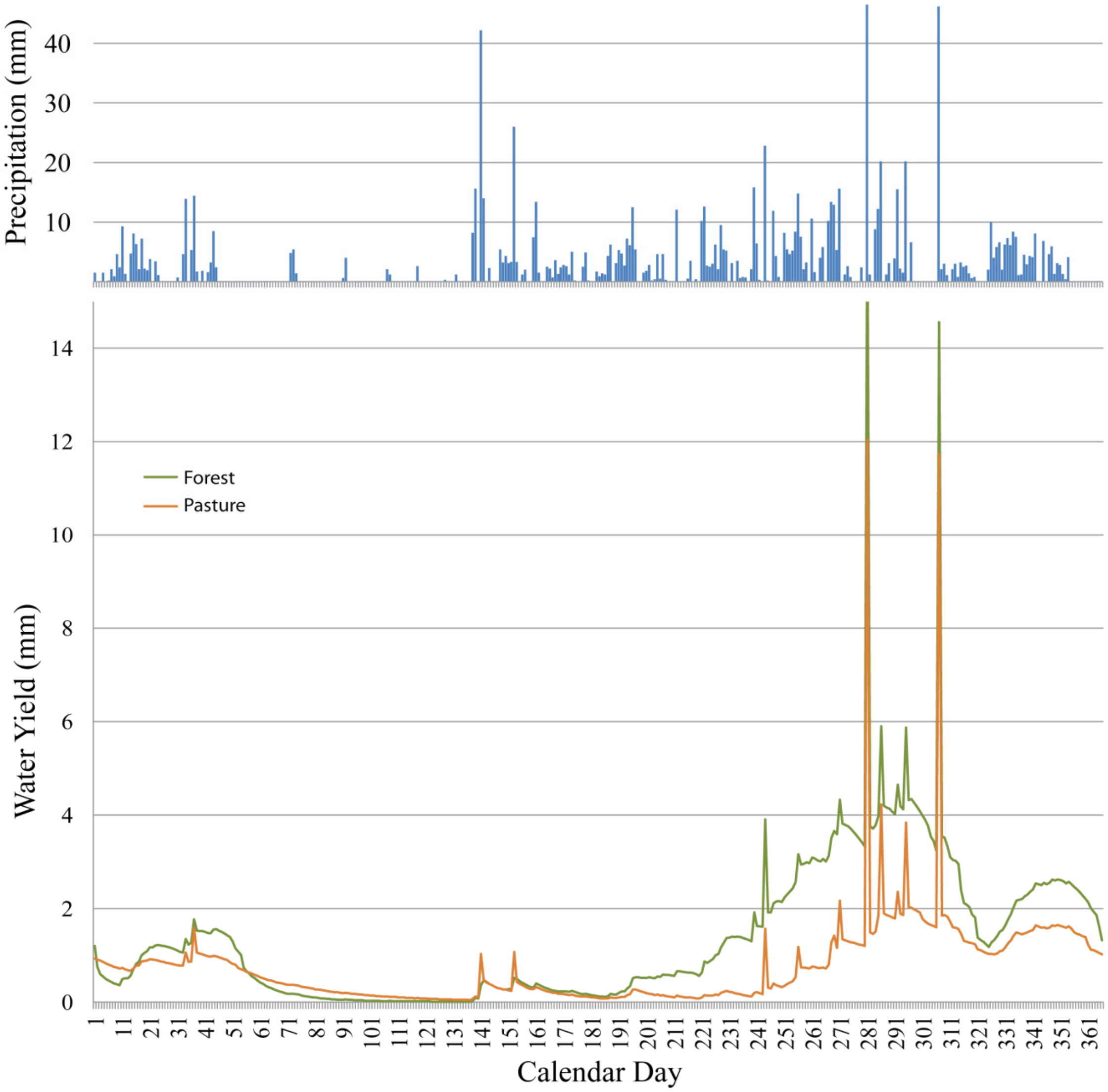


Figure 4.5. Example water yield results from SWAT model where the watershed is 100% pasture and 100% forest land cover.

The absence of calibration data made fine-tuning of the model impossible; because of this, water yields given by the model may not reflect actual water yields in the catchment. However, the relationship between water yields from the different land cover categories remained consistent throughout the range of parameters, lending more credibility to the relative results.

Results from evapotranspiration and soil water from the varying land covers are consistent in calling into question the forest-as-sponge narrative. From this data, it seems likely that reforestation will either fail to change or will decrease dry-season water yield in the catchment. Results from water yield are inconclusive, however, and probably reveal the limitations of the SWAT model as much as they provide clear guidance on dry season runoff. This underscores the difficulty, even with sophisticated modeling tools, of predicting outcomes of land use on low flows.

One limitation of the model is its inability to account for cloud-interception. Although the Sasle catchment probably receives a very limited proportion of its overall water budget from cloud interception, some regions of montane cloud forest experience strong impacts of this type of precipitation on a seasonal basis (Mulligan & Burke, 2005). Because this water input is dependent on tree canopy cover, the model could be underestimating water input in forested land cover types, particularly during months of lesser rainfall.

Regardless, the model indicates that partial conversion of the watershed from one land cover class to another has a relatively small impact on water yield, particularly during the dry season. The analysis of satellite imagery demonstrated that there has been a reduction in forest cover in the Sasle catchment on the order of 7% over the past 25 years. Modeling of ‘real’ land-use scenarios from 1985 and 2011 using the results of the aerial imagery analysis (Fig 4.6) reveals that the changes in water yield associated with this scale of land-use conversion are likely to be very small. Land conversion would have to be much more extensive for the effects on water yield to be felt by residents, and even then impacts would mostly be felt during the wet season.

Similarly, reforestation efforts, as planned by the local NGO, are unlikely to produce significant changes to water yield in the catchment. Changes in water yield with reforestation could be imagined as a reversal of the changes modeled between 1985 and 2011 in Fig 4.6, and changes in water yield would probably be accordingly small. Any changes that did occur in water yield, however small, would not represent the desired increase in dry season water yield sought with reforestation efforts.

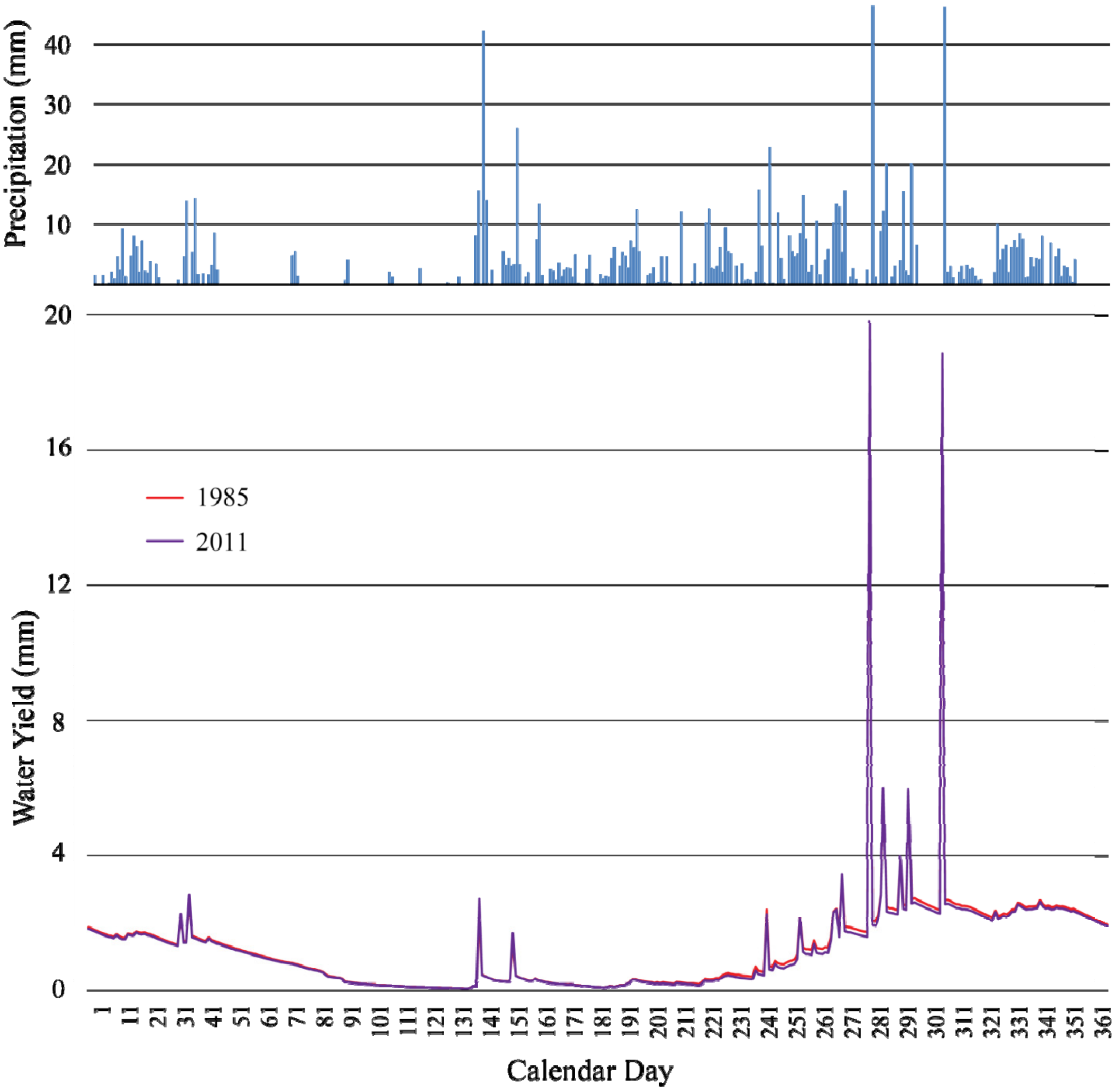


Figure 4.6. Example water yield results from SWAT model for mixed land use using 1985 and 2001 Scenario 2 results.

CHAPTER V

SO WHAT?

The forest-as-sponge narrative is almost ubiquitous in Central America. In the face of severe complexity, the narrative provides clarity of direction for water managers. It fosters forest conservation and provides incentive at a local scale for the implementation of forest conservation practices. It also provides indirect support for international policy movements such as IWRM and provides a simplistic recourse for governments and development agencies looking to legitimize development projects.

Following the logic of the forest-as-sponge narrative, resource managers in many parts of Central America are using reforestation programs as way to dampen dry season water shortage. Many forest programs related to water resource management focus their efforts on headwater areas – the generally steep, agriculturally marginal land located farther from roads and economic centers. These areas of focus are also, in general, where the poorest people live (CGIAR, 1997; Pagiola et al., 2005). A recent World Bank study identified these small, headland watersheds as critical areas of focus for research and policy (Nelson & Chomitz, 2004).

The Sasle basin in central Nicaragua represents a typical example of the way in which the narrative is being used in small, upland catchments. In Sasle, a local NGO is working with the communities living in the area to promote reforestation and increased use of shade-grown coffee as a means to eliminate water scarcity in the dry season. The NGO is working primarily with small land-holders who are affected by water shortages. However, results of both the modeling exercise and generalizations from past scientific research indicate that reforestation will not increase water availability in the dry season, and in fact is likely to slightly decrease availability. Although the magnitude of this decrease is may not be significant to water uses in the catchment, management objectives will not function as intended because the prescribed management practices will not result in the desired increase in water quantity.

Managing the conflict between these narratives is not an easy proposition. Because the forest-as-sponge narrative is functioning as a development narrative, it is not likely to disappear, particularly without presenting an equally simplistic and prescriptive narrative with which to replace it (Roe, 1991). The modeling results underscore the complexity of the relationship between land use and streamflow, especially low flows. Evapotranspiration and soil water results suggest that forests decrease dry season streamflow, but water yield results are inconclusive. In the case of near-zero water yields during the dry season in the Sasle watershed, absolute differences in water yield from altered land cover are unlikely to be appreciable. However, this result may or may not hold true for other catchments.

In other words, there is no simple, prescriptive solution to counter the forest-as-sponge narrative and its role in guiding policy. Because forests are useful for so many other reasons, suggesting deforestation of watersheds to combat water scarcity is both an ecologically and economically dangerous proposition, and one that may not always produce the desired results in dry-season water yield. The existence of montane cloud forests makes the relationship between forest cover and water yield more complicated, and would likely require different considerations by resource managers than other forest types.

On the other hand, doing nothing to address the conflict between the two narratives ignores the parts of the forest-as-sponge narrative that may be coercive and unethical. In certain forest management scenarios, poor, marginalized people are unfairly used in an international struggle over ideas and power. In some headwater catchments such as Sasle, resource-poor rural farmers are persuaded to convert productive land to forest for the purpose of increasing dry season water supply, but in reality they receive no such benefit from this conversion. The recommendation on the part of NGOs or other organizations to increase forest cover may be well-intentioned. However, the ultimate driver of these recommendations may be the chain of funding from global aid organizations such as the World Bank that now require reforestation projects to accompany water development projects.

My overall conclusion from this study is one of two-fold caution. First, scientists should be cautious about the implications of refuting the narrative to avoid undermining useful institutions. The forest-as-sponge narrative is used to accomplish work, and attacking the narrative without tact could threaten the ideas and institutions that have made use of it. Moreover, the narrative may, at times, accurately predict the impact of land cover change on hydrology, most notably in areas of montane cloud forest. Although the bulk of scientific evidence refutes the narrative, researchers should keep in mind the complexity of natural systems and avoid disregarding place-specific environmental understandings in favor of their own socially produced knowledge.

On the other hand, resource managers promoting forest conservation and restoration need to be cautious about what they promise in terms of water yields turn a critical eye to the way the forest-as-sponge narrative is being used. Although managers may approach their work with good intentions, the narrative in which they participate is part of a large socio-political landscape that may contain elements of coercion. With this paper I hope to call attention to the power structures formed and propagated by use of the narrative and the very real possibility of unintended outcomes following its use.

There should also be increased dialog between scientists and resource managers. Scientists should seek avenues of communication with development organizations outside the arena of scientific presentations and publications, which are unlikely to spark continued cooperation or dialog. Although the development narrative may persist in spite of criticism, continued interaction between scientists and policy-makers may at least bring some awareness to the existence of conflict between these narratives and some meaningful reflection on the way the narrative is being used. Local people in the areas being studied should be included in this dialog, and should under no circumstances be considered passive recipients in the production of knowledge or policy.

More broadly, using a geographic lens to examine the contention between narratives describing relationships between land cover and streamflow can provide deeper insight into management issues. Geography has the advantage of examining issues across scales and disciplines in order to arrive at a deeper understanding of origins and implications. To simply examine the factual validity of the narrative of the sponge is to miss what is most interesting and important about it. The narrative of the sponge is participating in socio-political and ideological struggles at multiple scales. Recognizing the forces at work in the narrative is an important step in negotiating how to address the narrative.

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