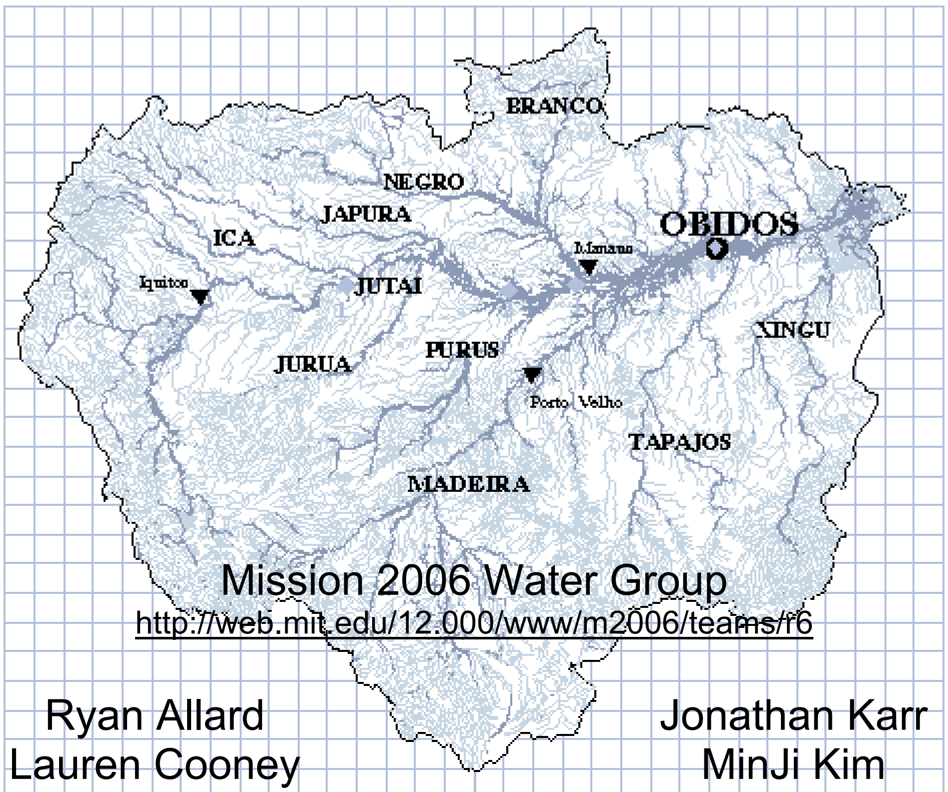
“State of the Water of the Amazon”



Mission 2006 Water Group

http://web.mit.edu/12.000/www/m2006/teams/r6

Ryan Allard
Lauren Cooney
Katrina Cornell

Jonathan Karr
MinJi Kim
Melanie Michalak

December, 2002

Table of Contents

I. Introduction

Solving Complex Problems grew out of concerns from the MIT faculty about the freshman year. The class was proposed as an experiment in freshman education by Professor Kip of the Earth and Planetary Sciences Department. Professor Hodges hypothesized that given complete control of their education, freshman would not only succeed, but flourish with enthusiasm. The first incarnation of the class, Mission 2004, challenged students to "develop a viable mission plan for the exploration of mars with the aim of finding evidence for the present or past existence of life." For the second year students were challenged "to design permanent, manned, underwater research laboratories and to develop detailed research plans for the first six months of their operation." Now in the third year of the experiment, the class of 2006 was challenged to "develop a way to characterize and monitor the well-being of one of the last true frontiers on Earth – the Amazon Basin rainforest – and devise a set of practical strategies to ensure its preservation."

The water group grew out of the need to effectively complete this mission. The class felt it necessary to divide ourselves into nine groups, each composed of four to seven students. Each group was then charged with a specific responsibility to the greater mission. In particular, the water group's goals have been to analyze the hydrologic cycle, monitor the chemical composition of the water, and examine the effects of human development in the Amazon Basin rainforest.

The purpose of this document is to summarize the water group's findings on the Amazon Basin rainforest water system. Particular emphasis is placed on the hydrologic cycle, aquatic biota, sedimentology, and the effects on these processes by deforestation, pollution, hydroelectric power plant construction, and mining.

Hydrologic Cycle

Our approach to the hydrologic cycle has been to analyze the cycle in terms of the flux of water into and out of the system, as well as the evolution of water inside the system. This translates into studying precipitation, precipitation recycling – evaporation and evapotranspiration, and river flows. This approach has led us to identify two major trends in the hydrologic cycle. The first of these trends is decreasing atmospheric transport of water vapor both into and out of the system. This is believed to be associated with relaxed southeasterly trade winds, a decreasing east-to-west pressure gradient, and a general warming of the sea surface temperatures in the equatorial South Atlantic. The second trend we identified is increasing internal recycling of precipitation and basin-wide precipitation.

Aquatic Biota

Our approach here was to identify the effects on aquatic biota by human development, with particular emphasis on artificial water management. Under this research area we also explored the possibility of using parasites as a proxy for measuring water quality and pollutions levels.

Sedimentology

Our approach to sedimentology was similar to that of aquatic biota, identifying the effects of human development, an in particular damming on the transport of sediment.

Deforestation

From what we have read and learned, deforestation is the principle problem facing the water system of the Amazon Basin rainforest. Deforestation affects all abiotic and biotic systems, disturbing the natural equilibrium of the region. For example, one effect of deforestation on the hydrologic cycle is to deprive the soil of important nutrients, as rainfall easily washes away the nutrient-rich top soil. This is possible because deforestation removes the trees that secure the soil to the land. Deforestation also has the effect of decreasing evapotranspiration, precipitation, and total runoff.

Pollution

Another major threat to the health of the Amazon Basin rainforest water system is pollution and in particular, mercury. Gold mining, which releases mercury both into the atmosphere and into the rivers, is one of the major causes of excess mercury in the water system. At times, the rate of production of mercury equals that of gold. Excess mercury in the water system is also caused by the recent colonization of the drainage basins and the growing exploration of land in the central Amazon. These actions both disturb mineral and organic matter cycles, including that of mercury. This results in increased exportation of fine particulate matter from the soil surface to drainage waters. Consequently, bioaccumulation occurs, whereby animals in the Amazon Basin's rivers slowly accumulate mercury in their bodies. Higher-order species of the food chain then accumulate mercy stores in their bodies by consuming lower-order species. It is easy to see then that humans will exhibit supernormal concentrations of mercury in their blood streams from eating contaminated fish.

Pollution

In addition to releasing mercury into the environment, mining releases nickel, chromium, copper, and arsenic. Acid mine drainage contains dissolved and particulate metals in toxic concentrations that affect the pH of streams and mobilize metals. Malaria is a secondary result from the fact that stagnant water often accumulates at mining sites. These pools easily become mosquito breeding ground.

Hydroelectric Power

A third major perturbation to the water system of Amazon Basin rainforest is the construction of dams. Hydroelectric Dams affect the river in the following detrimental ways: 1) Create water reservoirs/stagnant pools, 2) Increase water temperature, 3) Increase flooding, 4) Increase eutrophication, 5) Increase gas formation, 6) Decreased water oxygen content, 7) Increased siltation, and 8) Increased phosphorous and nitrogen content.

In summary, humans are reeking devastating effects on the health of the water system of the Amazon Basin rainforest. Estimates show that if deforestation continues at its present rate, the region will be completely deforested within the next century. Even if the rate of deforestation is slowed, some forecast that past a certain point, the rainforest will be unable to support itself, leading to self-destruction. Clearly, action must be taken now to reverse these trends in order to preserve the Amazon for future generations.

II. Water Cycle

A. Introduction

The hydrologic cycle is a very important process in the proper functioning of the Amazon River basin. The most visible part of this cycle is the river itself. The river is 4,000mi in length, carrying approximately 20% of all of water discharged to the Earth's oceans. The river originates in the high Andes Mountains, approximately 100mi west of the Pacific Ocean and travels east, terminating at the Atlantic Ocean. At the main outlet of the river, north of Marajo Island, the river is 40mi wide. At flood-stage, the river discharges 6,180,000ft^3 at its mouth. The volume of water carried by the Amazon is so great that the salinity of the Atlantic Ocean is diluted within a 100mi radius from the terminus of the river.

The Amazon River is fed by a large network of over 1,000 tributaries. Seven of these tributaries are greater than 1,000mi in length, the largest of which is the Negro River. The Negro River alone carries 20% of the discharge of the Amazon River. The Amazon River's tributaries can be roughly divided into three categories: blackwater, whitewater and clearwater (Saliot et al, 2001). Blackwater tributaries originate in the ancient crystalline highlands. Examples of blackwater rivers include the Jari, Trombetas, Negro, Tocantins-Araguaia and Xingu Rivers. These rivers are termed "blackwater" because they originate from acidic rains that are rich in humus and nutrient poor. Whitewater rivers, such as the Madiera are categorized by high sediment concentrations. Clearwater rivers like the Tapajos have slowed water rates where the sediment is allowed to settle.

The Amazon Basin rainforest covers an area of 2.3 million mi^2. At its widest part, it rainforest stretches 1,725mi. The basin includes parts of several nations, including Brazil, Peru, Columbia, Ecuador, Bolivia, and Venezuela. Brazil, which encloses 2/3 of the basin, was chosen to be the focus of the Project Amazonia class.

The Basin can also be roughly divided into two broad categories: lowland and upland. Lowland areas principally border the Amazon River itself and its tributaries and are 12-30mi wide. These areas are characterized by a yearly flooding cycle. The other 2/3 of the basin is considered upland. Upland regions are covered by immense rainforests that transition to dry forests and savannas in the West. Upland regions may also be described as "gently undulating hills." These areas are composed of layers of alluvial soil deposited as much as 2.5 million years ago and contain many shallow oxbow lakes[1] and wetlands. The average rainfall for upland regions is 60-120in/yr[2].

B. Rainfall

Precipitation arises from sources both within and outside the Amazon River basin. Sixty-four percent of water vapor flux into the Amazon comes through the eastern border of the basin. The remaining 36% enters through the northern border of the basin. Little water vapor enters the Amazon Basin from the west because the Andes Mountains serve as an effective barrier to storm systems moving eastward from the Pacific Ocean. At the same time, this also means that little water vapor escapes the basin through its western border. Water vapor entering the Amazon through the eastern and northern borders together account for approximately 50% of the precipitation in the Amazon. The remaining 50% comes from

---

1 Oxbow lakes are generally formed from mature rivers which begin to curve, cutting and eroding the outside of the curve. At the same time, sediment deposits on the inside of the curve. These two mechanisms arise from the fact that the flow of water is more rapid toward the outside of the curve. Over time, as erosion and deposition continue, the curve becomes larger and more circular. Ultimately, the loop of the curve reaches a diameter approximately five times the width of the stream and the river begins to cut the loop off by eroding its neck. Finally, the river breaks through a cutoff and forms a new streambed. The result is a crescent-shaped lake that looks like an abandoned river meander. Such lakes are called oxbow lakes because they look like the bow part of the yoke used with teams of oxen (Rosenberg, 2002). Eventually, oxbow lakes are silted up to form marshes and finally meander scars, marked by different vegetation or the absence of cultivation. The lakes commonly are filled with clay-sized sediment that is less easy to erode than surrounding material and thus may cause a more complex meandering system in its parent stream (Oxbow lake, 2002).

precipitation recycling within the Amazon Basin rainforest -- evaporation and evapotranspiration ("Amazon River", 2002).

Rainfall-producing mechanisms can roughly be divided into five scales -- continental, sinoptic, subsinoptic, meso-scale, and micro-scales. Each of these mechanisms is responsible for a different type of precipitation scheme. Our review of these mechanisms proceeds in the order of diminishing scale (Molion, 1991).

At the continental scale, 80-90% of solar radiation absorbed at the surface is used to evaporate water[2]. The remaining 10-20% is responsible for heating the air[3]. The intertropical convergence zone in the Atlantic (ITCZA) as well as the convergence of Northern and Southern hemisphere trade winds function at this scale (Molion, 1991).

The sinoptic scale (1000km) is the next smaller scale. At this scale, Southern hemisphere cold fronts or frontal systems, penetrate into Amazonia any time of the year. During the winter, these systems are characterized by a sharp 15-20º temperature decrease, lasting 3-5 days. During the summer, these systems are generally NW-SE oriented and cross the coast at 15-25ºS. It is believed that Northern hemisphere frontal may also have similar effects (Molion, 1991).

At the subsinoptic scale (500-1000km), instabilities or squall lines in the atmosphere can cause precipitation. The highest frequency of such instabilities occur in July. These squall lines occasionally propagate inland, possibly due to convergence of sea breeze. These instabilities may also be associated with waves in the trade wind field triggered by the deep penetration of frontal systems over the subtropical Atlantic (Molion, 1991).

Meso-scale (100km) precipitation is caused by convective cells and clusters of Cbs[4]. Precipitation caused by such cells is characterized by a high intensity and short duration in scattered locations. Micro-scale (1-10km) precipitation is caused by small convective cells that form during the morning hours and precipitate around 14-15hrs local time (Molion, 1991).

Pacific and Atlantic Ocean Surface Temperatures

Precipitation in the Amazon is affected by land alterations such as clear-cutting and farming. Certain changes to the land and soil will cause flooding, others will cause drought. Sea surface temperature of the Atlantic and Pacific oceans also plays a role in influencing the rainfall of the Amazon Basin region. When sea surface temperatures drop, floods result and when the temperatures increase, drought conditions are prevalent.

Three ocean regions affect the rainfall in the Amazon: 1. Atlantic Ocean 2. Eastern Pacific Ocean and 3. Western Pacific Ocean. The most influential of these three is actually the Western Pacific region, even though evaporation has to travel across the Andes Mountains. The Atlantic and eastern Pacific regions have similar, weaker effects on the rainfall of the Amazon (Shaw, 1999).

Variations in rainfall

On a decadal scale, water vapor input into the Amazon River basin has been experiencing a decreasing trend since the 1960's. This trend is believed to be associated with relaxed southeasterly trade winds, a

2 Latent heat
3 Sensible heat
4 Cumulonimbus clusters are mesoscale cloud phenomena with an average diameter of approximately 200km. They are often generated when the convection temperature of the surface is reached. They dissolve during the evening. The highest frequency is in summertime over land, but they also appear over sea during the whole year, at any time during day or night ("Cumulonimus Cluster (CB)," 2000).

decreasing east-to-west pressure gradient, and a general warming of the sea surface temperatures in the equatorial South Atlantic (Costa et al, 1999).

On a yearly scale, precipitation variability may be attributed to the El Niño-Southern Oscillation (ENSO) as well as several other secondary factors. Secondary factors include the strength of the North Atlantic high, the position of the ITCZA, and the sea surface temperature of Atlantic Ocean. Precipitation lags behind ENSO by 3-4 months, with river discharge lagging an additional 3 months. This additional lag is likely due to the contribution from subsurface drainage since surface runoff tends to occur at a much shorter timescale. Soil water storage similarly follows precipitation by approximately 1-2 months (Costa et al, 1999).

On a season cycle, precipitation has been observed to vary up to 5mm/day, with runoff vary up to 2mm/day and evapotranspiration remaining constant (Costa et al, 1999).

Rainfall evolution

The simplest models of the flow of water through soil take advantage of the fact that the surface soil can be divided into three major layers. The first of these layers includes the top soil. The second layer extends to rooting depth (d_2) and the third layer extends to the total soil depth (d_3). The sum of the water saturation of the three components is equal to the total rainfall to reach the land surface. The relationship

$$\frac{\partial w_1}{\partial t} = \frac{C_1}{p_w d_1} * (I - E_g) - d_1$$ **Equation 1**

$$\frac{\partial w_2}{\partial t} = \frac{1}{p_w d_2} * (I - E_g - E_{tr}) - K_2 - d_2$$ **Equation 2**

$$\frac{\partial w_3}{\partial t} = \frac{d_2}{d_3 - d_2} * (K_2 + d_2) - K_3$$ **Equation 3**

between water saturation and rainfall for each of the layers can be described by the following three mathematical equations (Engman, 1991).

A more physically realistic general circulation model (GCM) developed at the NASA / Goddard Institute for Space Science (GISS) introduces a canopy resistance and a six-layer soil system. This new scheme also allows runoff to travel from a river's headwater to its mouth according to topography and other channel characteristics. This model also produces more realistic evaporation statistics, taking into consideration conservation of mass, momentum, energy, and water vapor (Marengo et al, 1994).

The water budget equation for the atmosphere is also related to precipitation (P), evapotranspiration (E), the vertically integrated moisture convergence (C).

$$\frac{\partial w}{\partial t} = -P + E + C$$ **Equation 4**

C. Evaporation

Evaporation can be indicated by a measure called the precipitation recycling ratio (*p*). This ratio is the contribution of evaporation within a region to precipitation in the same region. A high precipitation recycling ratio estimate is not sufficient to conclude a strong role for land surface hydrology in the regional climate. Rather, it suggests a strong potential for significant changes in surface hydrology to impact regional climate (Eltahir et al, 1994).

The following model makes two assumptions: 1) atmospheric water vapor is well-mixed, and 2) the rate of change of storage of water vapor is negligible compared with water vapor fluxes at the time-scale for which the model is applicable. The model supposes two distinct relationships for water vapor evaporation, that within the region, and that outside the region, yielding the equation,

$$p = \frac{lw + E}{lw + E + lo}$$ **Equation 5**

where inflow is represented by I, evaporation is represented by E, and the subscripts $_o$ and $_w$ represent outside the region and inside the region, respectively (Eltahir et al, 1994).

Careful observation of evaporation data has led to the conclusion that the atmosphere above the Amazon Basin is not a closed system. Data suggest that there is a significant migration of moisture out of the basin. Furthermore, this flux out of the basin accounts for only 68% of the flux into the system. This implies that the outflux of atmospheric moisture from the basin may contribute important input to the hydrologic cycles of the surrounding regions. Furthermore, changes in the Amazon Basin evaporation levels may potentially affect the moisture supply and rainfall of surrounding regions (Eltahir et al, 1994).

The contribution to rainfall of precipitation recycling is largest to the west and south. The maximum rate of recycling occurs at the southwestern corner of the basin, where greater than 50% of precipitation can be attributed to evaporation (Eltahir et al, 1994).

D. Evapotraspiration

Mechanisms controlling changes in evapotranspiration are primarily driven by changes in albedo[5], surface roughness[6] and the depth of water available to plant roots. For example, increased albedo inhibits absorption of the incoming solar radiation, reducing the available energy for latent-heat exchanges (Roche, 1991).

The Amazon rainforest is highly efficient in recycling water vapor back into the atmosphere. Measuring this parameter however, is has proved extremely difficult. One reason for this is that evapotranspiration levels are highly variable across the Amazon Basin as evidenced by the following data:

- 610mm/yr in the semi-arid Rio Grande basin
- 1520mm/yr in the Orthon River basin
- 780mm/yr in Andean part of Beni River basin
- 1220mm/yr in oriental basins of Mamoré River
- 800mm/yr in the Bolivian Andean part of the upper Madeira River basin (Roche, 1991).

Results of evapotranspiration are summarized below, showing great variability due to great difficulty in making precise measurements.

---

[5] Albedo fraction of light that is reflected by a body or surface (Albedo, 2002).
[6] Surface roughness characteristics are described by the root mean square (rms) height difference *s* from a given datum, the correlation length *l*, and the correlation function (Cosyn, 2002).

Table 1: Hydrologic cycle of the Amazon Region (Nobre, 1991)

Research	Rainfall	Transpiration			Evapotranspiration			Runoff	
	mm	mm	%	mm/day	mm	%	mm/day	mm	%
Marques et al. 1980	2328				1260	54.2	3.5	1068	45.8
	2328				1000	43.0	2.7	1328	57.0
	2328				1330	57.1	3.6	998	42.9
Villa Nova et al. 1976	2000				1460	73.0	4.0	540	27.0
					1168	58.4	3.2	832	41.6
	2105				1569	73.4	4.3	532	26.6
Molion 1975	2379				1146	48.2	3.2	1233	51.8
Ribeiro et al. 1979	2478				1536	62.2	4.2	942	38.0
					1508	60.8	4.1	970	39.2
Ipean 1978	2179				1475	67.5	4.0	704	32.5
					1320	60.6	3.6	859	39.4
Dmet 1978	2207				1452	65.8	4.0	755	34.2
					1306	59.2	3.6	901	40.8
Jordan et al. 1981	3664	1722	47.0	4.7	1905	52.0	5.2	1759	48.0
Leopolo et al. 1981	2089	1014	48.5	2.7	1542	74.1	4.1	541	25.9
Leopolo et al. 1982	2075	1287	62.0	3.5	1675	80.7	4.6	400	19.3
Shuttleworth 1988	2636	992	37.6	2.7	1320	50.0	3.6		
Able-2B 1987 (1 month)	290				157	54.1	5.2		

E. River Flow Volume

Introduction

Monitoring river volumes is an important method of calibrating hydrologic cycle models. The same techniques used to monitor river volumes may also be used to monitor vegetations densities. From this information, friction coefficients may be derived and used to further improve hydrologic models. Secondly, it is important to monitor river volumes in order to predict and give advance warning for floods further downstream. In particular, if the Mission 2006 class decides to create industrial zones along rivers. It will be important to know which areas are and are not susceptible to floods. Further, if frequently flooded cites are chosen, it will be important to be able to predict floods for those areas (Alsdorf et al, 2000).

Data

The following measurements were carried out on November 23 and 30, 1998:

- Gurupa
  - Mean water velocity range: 21 - 95 cm/s
  - Amplitude of water level fluctuation: 2.2m
  - Flow rate range: 31,200 - 104,000 m^3 / s
- Almeirim (width = 6500m)
  - Mean water velocity range: 21 - 95 cm/s
  - Amplitude of water level fluctuation: 1.4m
  - Flow rate range: 28,700 - 122,000 m^3 / s
- Obidos
  - Mean water velocity range: 21 - 95 cm/s
  - Amplitude of water level fluctuation: 3.41m
  - Flow rate range: 104,000 - 112,000 m^3 / s

Monitoring

One method for monitoring river flow rates uses an ultrasonic device called an Acoustic Doppler Current Profiler (ADCP). The most frequent problem with this technique is that it ignores a non-negligible river bottom displacement when calculating river flow. This uniformly leads to an underestimation in flow volume measurements. This error is commonly referred to as "moving bottom error." Recent studies into the problem have developed promising solutions which should be able to improve accuracy (Callede et al, 2000).

Data on river volumes can be best attained using remote sensing techniques[7]. These techniques promise vertical resolution of up to 10cm. The most promising of these techniques for monitoring water level changes is the interferometric synthetic aperture radar (SAR)[8]. This system however, is not applicable to bodies of water less than 2km wide, meaning such a system could only apply to the Amazon River itself and its major tributaries. An alternative approach uses a technique called airborne scanning laser altimetry or LiDAR to detect water level changes. This technique has already proven to be highly useful for measuring vegetation height, and so data taken from such a system would be particularly useful in modeling runoff (Cobby et al, 2001).

The two techniques have particular advantages over the Landsat, ERS-1, JERS-1 and Radarsats systems because of the frequency at which they can monitor rivers. These systems have the capability to monitor water changes up to every six hours, which is necessary for quickly detecting floods (Cobby et al, 2001).

F. Trends

Over the past twenty years, the hydrologic cycle has experienced a number of trends, which are likely to be indicators of the effect of deforestation on the whole Amazon River basin region. If changes in water vapor transport continue into the future, combined with decreases in evapotranspiration, all of the sources of water vapor into the Amazonian atmosphere will be significantly altered. In turn, this will have huge ramifications on the entire Amazon River basin ecosystem (Costa et al, 1999).

The first of these trends is decreasing atmospheric transport of water vapor both into and out of the system. This trend is believed to be associated with relaxed southeasterly trade winds, a decreasing east-to-west pressure gradient, and a general warming of the sea surface temperatures in the equatorial South Atlantic (Costa et al, 1999).

The second of these trends is increasing internal recycling of precipitation and basin-wide precipitation. This is occurring even as evapotranspiration and runoff have remained at a constant level across the entire basin. Annual mean atmospheric trends do exist for the eastern part of the basin. On a yearly scale, precipitation variability may be attributed to the El Niño-Southern Oscillation (ENSO) as well as several other secondary factors which include the strength of the North Atlantic high, the position of the intertropical convergence zone, and the surface temperatures of Atlantic. On the decadal scale, these factors are still important, but less so (Costa et al, 1999).

Over the 1960's and 1970's there was a general increase in Amazon River basin precipitation and river discharge. However, precipitation and river discharge over 1970's and 1980’s were average. One explanation for this decrease is the changes in the frequency and duration of the positive phases of the ENSO (Costa et al, 1999).

---

[7] Three types of differences between land and water can be detected by remote sensing: 1) emissivity, 2) reflection of natural radiation, and 3) reflection of satellite generated radiation. These first two differences can be measured passively whereas the third is measured actively. One problem with remote sensing is that systems operating in the visible, near-infrared or thermal infrared wavebands are incapable of penetrating cloud cover.

[8] Data was acquired over the central Amazon by the Space Shuttle imaging radar mission. This technique is used to measure subtle water level changes in an area of flooded vegetation on the Amazon flood plain. The technique makes use of the fact that flooded forests and floodplain lakes with emergent shrubs permit radar double-bounce returns from water and vegetation surfaces.

Deforestation

No one doubts that deforestation will have a devastating effect on the hydrologic cycle of the Amazon Basin. Research has clearly shown that deforestation of the Amazon will cause a decrease in precipitation of 25% or 1.4mm/day (Dickinson et al, 1992). From 1990-1993 rainfall decreased in almost every month, as evidence to this trend. However, reductions in rainfall will not occur uniformly across the basin. At some locations rainfall may decrease by up to 65%, whereas other locations (typically the mountainous regions of Peru and Ecuador) will experience increases in rainfall. Furthermore, changes in precipitation are not confined to the Amazon River basin itself. Evidence for this comes from the observation that during the southern summer and autumn there are large fluctuations in precipitation in eastern Brazil which seem to correlate with precipitation changes over deforested areas (Lean et al, 1993).

Research has also shown that deforestation of the Amazon Basin will cause an increase in evapotranspiration of 0.7mm/day. Similarly, total runoff will decrease by 0.7mm/day (Dickinson et al, 1992). Surface runoff however, will increase substantially, primarily as a result of decreased soil infiltration capacity and changes in the spatial distribution and intensity of rainfall (Lean et al, 1993). In addition, temperature will increase 1-4°C. This results from a decrease in surface roughness and a decrease in the amount of energy used to evaporate water at the canopy and soil surface levels (Dickinson et al, 1992).

In summary, these changes in the hydrologic cycle will be caused by:

1) Decreased surface roughness
2) Increased surface albedo
3) Changing soil properties
4) Decreased rooting depths, and
5) Decreased infiltration rates (Dickinson et al, 1992).

One conclusion that may be drawn from the observation that the reduction in precipitation is larger than the reduction in evapotranspiration is that the length of the dry season will increase. In turn, deforestation will become self-perpetuating (Henderson-Sellers et al, 1993)

Table 2: Model fields averaged over the simulation and over the Amazon Forest (Dickinson et al, 1992)

Field	**Control**	**Deforested**	**Change**
Daily Maximum Temperature (K)	304.1	306.7	2.6
Daily Minimum Temperature (K)	294.8	294.6	-0.2
Mean Surface Soil Temperature (K)	298.8	299.4	0.6
Precipitation (mm / day)	5.5	4.1	-1.4
Runoff (mm / day)	2.0	1.3	-0.7
Evapotranspiration (mm / day)	3.5	2.8	-0.7
Interception (mm / day)	1.3	0.8	-0.5
Sensible Flux (W / m2)	54.0	56.0	2.0
Absorbed Solar Radiation (W / m2)	215.0	212.0	-3.0
Net Longwave Radiation (W / m2)	59.0	74.0	15.0
Fractional Cloud Cover	.53	.46	-0.07
Relative Soil Moisture	0.7	0.4	-0.3

Table 3: Summary of Surface Variables for Control (C) and Deforested (D) Simulations Averaged over 3 years for Amazonia (Nobre et al, 1991)

Surface Variable	Control	Deforested	Percent Difference
Evapotranspiration (m/d)	3.12	2.27	-27.2%
Precipitation (m/d)	6.60	5.26	-20.3%
Soil Moisture (cm)	16.13	6.66	-58.7%
Runoff (m/d)	3.40	3.00	-11.9%
Net Radiation (W/m^2)	147.29	125.96	-14.4%
Temperature (C)	23.55	25.98	10.3%
Sensible Heat (W/m^2)	57.19	60.15	5.2%
Bowen Ratio	0.85	1.50	76.5%

G. Rainfall Monitoring

Trends in climate, like the ones described above, can be quantified by a number of different methods. One such method relies on river discharge records. River records however, may be skewed by land use changes and artificial means of flow control[9]. The method does offer the advantage of integrating spatial variability. An alternative method uses rain gauges. The effectiveness of this method is a function of spatial density (Costa et al, 1999). One problem with traditional rain gauges is that datasets created by such devices are extremely inefficient, as the devices are programmed to record the amount of rainfall over a set interval of time. Consequently, datasets are filled with huge numbers of extraneous zeros, making the datasets difficult to manipulate. One possible solution to fixed-interval recording is fixed-event recording. Under this scheme, the device records the amount of time over which a set amount of rain falls. This scheme eliminates the large amount of extraneous zeros, yielding leaner and more manageable datasets (Tan et al, 1991).

The effectiveness of rain gauges however, is limited by their spatial density and distribution. For rural areas such as the Amazon Basin rainforest, this density is particularly low. A more effective method of measuring rainfall takes advantage of satellites to monitor the entire Amazon Basin rainforest. Two types of satellite monitoring include infrared and microwave monitoring. The former determines rainfall amounts from cloud-top temperatures. The advantage of these systems that they are able to continuously monitor given region. The latter is more accurate in determining instantaneous rainfalls. The problem with microwave-based systems is that they are only capable of monitoring any given location two times per day. This method determines rainfall amounts from the distribution of hydrometeors within clouds (Sorooshian et al, 2000).

The most effective method of measuring rainfall is a combination of local and remote sensing. An example of this is the Climate Prediction Center merged analysis of precipitation (CMAP). This merged analysis is composed of two kinds of data: standard precipitation (STD) and enhanced precipitation (ENH). STD consisted of gauge observations, where as ENH consists of five kinds of satellite estimates. Specifically these estimates are:

1. Outgoing longwave radiation (OLR)-based precipitation index,
2. Infrared-based Geostationary Operational Environmental Satellite (GOES) precipitation index,
3. Microwave sounding unit,
4. Microwave scattering from Special Sensor Microwave/Imager (SSM/I), and
5. Microwave emission from SSM/I (Matsuyama et al, 2002).

[9] Dams, flow diversions, and river channelization

H. Evapotranspiration Monitoring

Theory

Constructing a hydrologic budget for the Amazon is an extremely difficult and imprecise task. In general, the three main factors to consider are precipitation, evapotranspiration, and surface runoff. More precise models also integrate zonal and meridional wind speed and specific humidity. The underlying principle in constructing such balances is that the long-term rate of precipitation (P) is equal to the sum of evapotranspiration (E) and runoff (R). Some studies, however, have noticed a small imbalance in this relationship, namely that P - (E + R) is -179mm/yr. The explanation given to account for this phenomenon is that water was artificially added to the basin during the reanalysis procedure.

Table 4 gives the water budget for the Amazon Basin rainforest.

Table 4: Mean water budget for Amazonia. The data are 12-month mean (January to December) values (Nobre et al, 1991)

	Total Precipitation (P) (mm/year)	**Evapotranspiration (E) (mm/year)**	**E-P**	**E/P**	**Precipitable Water (mm)**
Control	2464	1657	-807	0.67	37.7
Deforestation	1821	1161	-661	0.63	35.4
Difference	-642	-496	+146	-0.04	-2.3
Change (%)	-26.1	-30.0	+18.0	-5.9	-6.1

Using similar methods as those outlined above, one can estimate another measure of the hydrologic cycle, namely the precipitation recycling ratio (*p*). Estimates for the precipitation recycling ratio for the Amazon range from 25 - 52%. The value is related to average evapotranspiration (E) and water vapor input (I), though specific methods for calculating the ratio are disagreed upon. One such method is shown below.

$$p \equiv \frac{E}{E + I}$$ **Equation 6**

Another measure of the hydrologic cycle is called convergence (C). This is simply the difference between water vapor input (I) and output (O), such that C = I - O. Taking into consideration the entire land-atmosphere water budget and the principle of mass conservation, the long-term average convergence of should be equal to the discharge of water out of the basin (Costa et al, 1999).

Methodology

Evapotranspiration can be measured directly using a lysimeter. This device consists of a block of soil covered with vegetation. The block of soil is initially removed from the forest and placed into a container. Next the block of soil is returned to its original location so that the container as well as the soil is set into the ground. Over time, the input of precipitation is measured via rain gauges and the drainage output is recorded. During this same interval, the block of soil is frequently weighed to estimate the amount of water loss via evapotranspiration.

$$evapotranspiration \propto precipitation - draingage - \Delta mass$$ **Equation 7**

Although lysimeters may be effective in accurately determining evapotranspiration, on a large scale it would be impossible to implement such a design. Researchers therefore have come to use large scale measurements of rainfall to determine evapotranspiration levels. Typically rainfall data is gathered from satellites. Evapotranspiration is then determined using an algorithm.

Adding energy balance considerations, one can derive more accurate predictions of evapotranspiration and evaporation. For specific plants, a simple equation can be written to express the maximum evapotranspiration (ET_M) for that plant. This value is related to the maximum evapotranspiration for a reference plant (ET^0) such as green grass and a dimensionless coefficient for the specific plant (K_C).

$$ET_0 = A + BR_G + CR_GT_A$$ **Equation 8**

$$ET_M = K_CET_0$$ **Equation 9**

where A, B, and C are constants and R_g is the radiation that reaches the ground.

This however is just one estimation of evapotranspiration. Countless other studies have developed estimations based on similar principles. Another such equation relates evapotranspiration to net radiation (R_n), surface temperature (T_s), and air temperature (Ta).

$$ET = R_n + A - B (T_s - T_a)$$ **Equation 10**

where A and B are constants (Engman et al, 1991).

II. Aquatic Biota

A. Fish

Introduction

The Amazon River basin has a large number of fish and other aquatic lifeforms. The immense diversity of species in the Amazon River basin can be demonstrated by observing the number of frogs in the basin. For example, at a single site in Amazon rainforest in Santa Cecilia, 81 species of frogs have been recorded. For comparison, there is approximately the same number of frog species in the entire United States (Rainforest Ecosystems, Animal Diversity, 2002). Furthermore, every year, about 35 species of fish are discovered and named in the Amazon basin. Many new species have even been discovered unintentionally as a side effect of studies on known species. This diversity of the fish population of the Amazon River basin is due to three factors:

1) The size of the Amazon River basin, which enables many species of fish to flourish.
2) The location of the Amazon River basin near the equator, which is favorable to fish growth. Because the basin absorbs so much energy from the sun, there is a large aquatic flora population able to maintain a large fish population. In addition, the position of the rainforest near the equator also means that the amount of energy absorbed from the sun is fairly constant throughout the year. Thus, there is little seasonal variation, that is the temperature and day length are fairly stable throughout the year.
3) The low extinction rates of the Amazon Basin rainforest. Additionally, since the extinction rate is lower than the rate at which new species are introduced to the basin, the net number of species is increasing.

Miscellaneous

Fish from the Amazon are a popular export to Asian countries, especially Japan. They are also a key element in the diet of people living along the Amazon River. Because of the high protein content of their diet, inhabitants along the river are much less likely to be malnourished than rural people in regions without fisheries.

As the Amazon River rises, fish move through river channels into the floodplains. Some fish, such as the tambaqui, are specially adapted to the flooded forest environment. A keen sense of smell leads the tambaqui to fruit which has fallen from the tree tops to the water. The tambaqui are genetically adapted, with powerful jaws and teeth that enable them to consume fruit. Not only do they gain and store fat to last them through the dry season, but in the process they propagate the tree species by providing a dispersing mechanism for the seeds.

Over the past 15 years, naturalist Michael Goulding has noticed a steady decline in the size of many of the fish. This, together with increasing agriculture, raises concern about over-fishing and habitat depletion, especially in the lower Amazon where extensive agricultural production already exists and continues to expand (Hauser, 2002).

Affects on fish populations by water management

The reproductive success for both native and non-native river fish populations is related to the water flow of the previous year. Therefore, water flow manipulations can be a powerful tool for managing fish populations. Such manipulation can be accomplished using dams, flow diversions, and river channelization. Conversely, the implementation of artificial flow control means can have an adverse effect on fish populations.

Damned rivers can be divided into four main segments:

1) The upstream segment, which is largely unaffected by the dam.

2) The segment immediately behind the dam.
3) The segment immediately downstream of the dam; this segment of the river is most affected by the dam. In this section, native fish populations are the most severely affected, to the point that they may be dominated by non-native species.
4) The segment downstream of the dam. With increasing distance from the dam, and with the influx of other rivers and streams, the effect of the dam in this segment is decreasingly severe. Correspondingly, native fish populations are more successful with increasing distance from the dam (Brown et al, 2002).

B. Fish Monitoring

VHF Telemetry

VHF transmitters in the frequency range 173-174MHz with 1mW output are used to monitor the position of tagged animals. The transmitters can be detected from up to 6000m away, depending on the amount of intervening vegetation and the orientation of the transmitter. Receiving stations are commonly placed in the canopy level of the rainforest.

Researches have used VHF telemetry systems to monitor botos[10]. Over one four year period, one group of researchers was able to study the movement of the animals in yearly bases as well as their reproductive cycles and social behaviors, among other activities.

Although this is a very effective method for monitoring the location of aquatic life, this is a very labor intensive and expensive method. In addition, because of the high density of the rainforest, signals are often blocked, reducing their effective range. This means that animals will often move out of range of the receiving stations. Another problem the use of VHF telemetry this is that the receiving stations often become nests for bees and other insects (Martin et al.).

Robotic Boat

This method was initially developed as a less costly alternative to VHF telemetry. The entire tracking system can be contained in a 10' kayak hull, including subsystems that allow the boat to autonomously follow a tagged, swimming animal. GPS also is used to navigate and monitor the position of the boat. Acoustic transducers are used to locate aquatic life. The entire system has an endurance of 24hrs, meaning it operates on a one-day cycle. Because the kayak is only 10ft long, 27in wide, and 34lbs, the system is very easy to maintain. Moreover, the kayak-like shape also makes the device durable. Because this is currently an experimental system, no data is available yet (Goudey et al).

C. Parasites

Parasites are effective potential indicators of environmental quality due to the variety of ways in which they respond to anthropogenic pollution. Thus parasites provide valuable information about the chemical state of their environment through their presence / absence and ability to concentrate environmental toxins within their tissues.

Specifically, parasites are useful in two different ways. First of all, they are "effect indicators," that is they can reveal the effects of various pollutants on the abundance and distribution of fish. However, because there is a wide variety of factors which affect the population of parasites, parasites do not allow any conclusions to be drawn concerning the concentration of specific toxins in the environment.

One example of the use of parasites as an effect indicator is the Monogenean Trematode, which lives on the gills of fish. Because this parasite is in direct contact with both the surrounding environment and the host fish, it is a particularly good indicator species. In addition, its short lifespan means that it immediately reacts to environmental changes. Other effect indicator species include the *Dreissena* and

[10] Amazon River dolphins

Salmo gairdneri, which are hosted by zebra mussels and rainbow trout, respectively. These species are good indicators of the quality of water treatment in sewage plants. Dactyloyrus and Paradiplozoon are also effective indicators of the concentration of effluent resulting from pulp and paper mills.

Second, parasites can be used as "accumulation indicators"[11]. By looking at the concentration of environmental toxins within the parasites, we can monitor the environment. This method takes advantage of the fact that parasites usually have higher concentrations of metals in their bodies than their host has in its tissues. For example, the lead burden in the parasites is about 1000 times that of the host's muscle. This is because metal concentrations in parasites are likely to respond rapidly to changes in environmental changes.

For example, the presence of acanthocephalans had a significant impact on lead accumulation in the intestinal wall. The fish infected with acanthocephalans only half of uninfected chub's lead concentration. Acanthocephalans is a group of intestinal worms commonly found in fish. Adult worms live inside the intestine of the final host and absorb their nutrients across their tegument[12]. There are three major species: 1) Pomphorhyndchus laevis, 2) Acanthocephalus lucii, and 3) Paratenuisentis ambiguous. Among these, P. Laevis most rapidly reacts to changes in the environment. The mean concentrations of lead and cadmium in P. Laevis are respectively 2700, 400 times higher than in the muscle of the host and 11000, 27000 times higher than in water. Acanthocephalans can accumulate toxic metals from the aquatic environment to concentrations even surpassing those in Dreissena polymorpha[13] (Sures, 2001).

[11] Accumulation of toxins within parasites
[12] Acanthocephalans do not have mouth nor intestine
[13] Dreissena polymorpha is a kind of mussel. It is one of the best established accumulation indicators in fresh and brackish waters in Eruope and USA.

III. Sedimentology

A. Sediment transport and erosion

Each year the Amazon transports suspended sediment to the delta plain. On average, the sediment is composed of 1240Mt from Andean erosion and 3200Mt from flood reworked plain sediments ("Channel floodplain geomorphology along the Solimoes-Amazon River in Brazil.", by Leal A. K. Mertes, Thomas Dunne, Luiz A. Martinelli. From *Geological Society of America Bulletin*, September 1996.). Sediment exchange between the flood plain and channel also deposits sediment in the rivers. The main methods of this exchange are: band erosion, bar deposition, settling from diffuse overbank flow, and sedimentation in flood plain channels ("Exchanges of sediment between the flood plain and channel of the Amazon River in Brazil" by Thomas Dunne, Leal A. K. Mertes, Robert H. Meade, Jefferey E. Richey, Bruce R. Fursberg. From *Geological Society of America Bulletin*, April 1998). Different parts of the river exhibit different erosion and deposition patterns. In general, upstream there is sediment erosion in the main channel and deposition in the flood plain channels[14]. This leads to what is known as "scroll bar topography," that is terrain characterized by hundreds of long narrow lakes. Oxbow lakes in such areas quickly vanish as a consequence of this process. In contrast, in further downstream areas, channels are restricted by long-term, stabilizing levee building and flood plain construction, dominated by overbank deposition. This process buries scroll bar topography, producing a flat flood plain covered by a patch work of large, shallow lakes. Such flood plains are recycled in less than 5000 years, and at even faster rates further upstream ("Channel floodplain geomorphology along the Solimoes-Amazon River in Brazil.", by Leal A. K. Mertes, Thomas Dunne, Luiz A. Martinelli. From *Geological Society of America Bulletin*, September 1996.).

The combined exchanges of sediment transport define a "sediment budget." Such budgets estimate that an average of 2070Mt of sediment is exchanged per year. This sediment can be broken up into four groups: 1) Sediment entering the channel from bank erosion ~1570Mt/yr, 2) Sediment transferred from channel transport to bars ~ 380Mt/yr, 3) Channelized flow in flood plains ~ 460 Mt/yr, and 4) Diffuse overbank flow in the flood plain ~ 1230Mt/yr. In total, "deposition on bars and flood plain exceeded bank erosion by ~ 500 Mt/yr over a 10-16 yr period," meaning there is a net accumulation of sediment both on the valley floor and in the delta plain each year.

Understanding this accumulation of sediment over time can be important to understanding where pollutants such as mercury flow, and thus where the effects of such pollutants should be studied. Understanding the flow of nutrients provided by the regular deposition of sediment also helps to understand how a change upstream in sediment collection may effect the ecosystems surrounding the river. ("Exchanges of sediment between the flood plain and channel of the Amazon River in Brazil" by Thomas Dunne, Leal A. K. Mertes, Robert H. Meade, Jefferey E. Richey, Bruce R. Fursberg. From *Geological Society of America Bulletin*, April 1998)

B. The effect of hydroelectric power dams on the river

Reservoirs have both positive and negative effects on the upstream and downstream environments due to the modification of the natural flow conditions. These effects include higher temperatures, with little to no variation in temperature throughout the course of a year; increased forest flooding, critical situation in reservoir filling (from the sediment dropped when the water slows in the reservoir), decreased residence time, increased eutrophication, increased gas formation, corrosion of equipment and a decline in the water quality downstream. One possible solution that would negate these negative effects is hydraulic equipment to reaerate reservoirs ("Water Quality Simulation in Reservoirs in the Amazon Basin: Preliminary Analysis" by Carlos Eduardo Morelli Tucci. From *Water Management of the Amazon Basin*).

---

[14] An order of magnitude smaller than the main channel

C. Monitoring

A NASA project called the "Global Rainforest Mapping project (GRFM) by an orbiting spacecraft using radar imaging, (Japanese JERS-1 Synthetic Aperture Radar (SAR))" is capable of monitoring sediment flows. The first SAR mapping of the Amazon (during low flood season) took 62 days. Another was done during high flood season. The advantage of SAR technology is its ability to be used at night and to see through clouds. This is particularly important as some areas of the rainforest are under perpetual cloud cover. This data may be useful in trying to model the carbon cycle and climate change. In addition, it can be used as a baseline with which to compare future data collections (http://southport.jpl.nasa.gov/amazon/imagebrowser/jamms.html).

Optical Backscatter (OBS)

This method uses photodiodes positioned around an emitter to measure the light reflected by a given sample. The method requires an empirical calibration to convert the measured backscatter to a concentration. Measurement sample volume "is on the order of several cubic centimeters," meaning it can best measure 200-400µm particles, and concentrations of up to 100g/L. These devices are readily available and relatively inexpensive. However, they require manpower to run the tests. There are many slight variations to this method.

Acoustic

This method takes advantage of the fact that sediment reflects a certain amount of sound depending on its concentration and particle size and the frequency of the sound. Short bursts[15] of high frequency[16] are emitted from a transducer. Using multiple frequencies, it is possible to determine both the particle sizes[17] and concentrations[18]. This technique can also be used to measure a vertical profile of sediment concentrations for depths of 1-2m. This acoustic technology is still under development.

Spectral reflectance

Suspended sediment concentrations are measured using the amount of radiation reflected from a body of water and the properties of that water. This can be measured using a handheld, airborne, or satellite based spectrometers. One major advantage of satellite-based spectrometers is the ability to measure a much larger area[19]. Because of the sheer size of the Amazon Basin rainforest, satellites are clearly a better choice.

Digital optical

"A charge-coupled device records the sediment/water mixture in-situ." Sediment can be analyzed for size as well as the concentration of suspended sediment particles. The technology is still in the development stage. Currently the technology is dependant on light penetration. Ideally a computer could remotely analyze the light penetration, and hence the soil size and concentrations ("Surrogate Techniques for Suspended-Sediment Measurement" by Daniel G. Wren, Roger A. Kuhnle).

---

[15] 10µs
[16] 1-5Mhz
[17] 62-2000µm
[18] Up to 30g/L
[19] 1-1,000,000m^2

IV. Deforestation

Deforestation, or the clearing of trees, is a problem that affects the entire Amazon Rainforest ecosystem. Studies have attempted to model the effects of deforestation, yielding horrific predictions for the future of the Amazon Basin rainforest, assuming that the current pattern of deforestation continues unabated. To examine the effects of deforestation more closely, one 1990-1993 study replaced tropical forest and savannah lands with pastures in South America, north of 30°S. The most prominent affects on the water ecosystem were as follows:

Deforestation caused an increase in erosion and flooding. Because tree root systems hold the soil together, the removal of those roots leads to an increase in the rates of flooding and erosion. The removal of trees also means that less water will absorbed during the rainy season. The rainy season therefore, can have devastating effects as heavy rains will be able to wash away vital, nutrient-rich topsoil. This in turn leads to decreased biodiversity and species richness.

The method of slash and burn deforestation has a strong impact on the carbon cycle. On average, the burning of one acre of tropical rainforest releases 180 metric tons of carbon. In the atmosphere this carbon bonds with oxygen to form CO_2.

The methane cycle is also affected by deforestation. Methane is created by floating meadows[20] and flooded forest, both of which are encouraged by deforestation. Researcher Laura Hess describes the role of floating meadows in the methane cycle: "Floating meadows are very productive, floating masses of grass. The[ir] stems elongate as the water rises and a canopy develops at the top of the water. Grasses can reach several meters in length and float at the top of the water. As water levels recede, the stems begin to decay. This causes a bubbling of methane and high methane emissions" (Hauser, 2002). Deforestation can also cause increased methane production as a result of increased flooding, and therefore wetland expansion. Methane in these wetland areas is produced as the water in these areas cuts off the oxygen supply to the soil. This results in anaerobic fermentation, a byproduct of which is methane.

[20] Grass colonies in the water that form large clumps, flood plants called macrophytes.

V. Pollution

A. Acidification and pH

Acidification is a naturally occurring process in nature. In high rainfall tropical areas, natural acidification of soils and surface waters is common. However, tropical areas are especially sensitive to further acidification by increased atmospheric deposition of sulfate and nitrate ions (Rodhe et al, 1988). The following describes the three necessary conditions for the acidification of an aquatic ecosystem by atmospheric deposition:

1) Atmospheric deposition of sulfate or nitrate or of some anion must increase.
2) Adjacent soils to the aquatic ecosystem must not retain the anion that is increased in deposition.
3) Aquatic ecosystem must have a low alkalinity for acidification to result in biological damage (Rodhe et al, 1988).

The major rivers and tributaries of the southeastern region of Brazil have varying levels of pH. Figure 1 below is a map of the major rivers of the southeastern region of Brazil. Table 5 gives the pH and SO_4^{-2} and NH_4^+ concentrations for these rivers and their tributaries (Moreira-Nordemann, 1988).

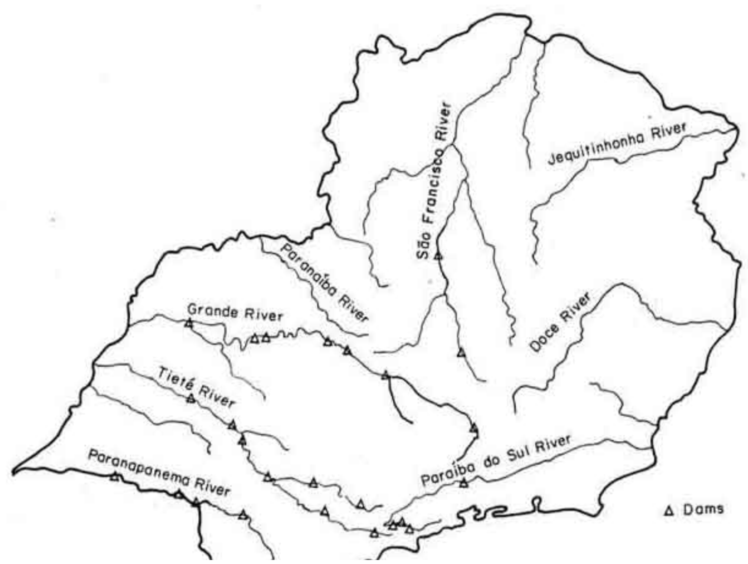


Figure 1: Rivers of Southeastern Brazil

Table 5: São Francisco River and Tributaries (T); minimum and maximum values based on one sample per year (1982-1983) at several points on each river **(**Moreira-Nordemann, 1988)

River Name	pH	SO_4^{2-} (mg/L)	NH_4^+ (mg/L)
Sào Franciscó	4.8 – 7.8	< 1.0 – 16.2	0.1 - 0.5
Sào Miguel (T)	7.6 – 7.7	< 1.0 – 2.7	< 0.1 – 0.5
Parà (T)	7.2 – 7.6	< 1.0 – 5.0	0.1 – 0.3
Lambari (T)	7.3 – 7.5	< 1.0 – 3.0	--
R. das Velhas (T)	6.5 – 8.7	< 1.0 – 55.0	< 0.1 – 2.1
R. Jequitai (T)	7.1 – 8.0	1.2 – 2.3	0.1
Pacuí (T)	7.2 – 7.8	1.8 – 2.1	< 0.1 – 1.0
Prata (T)	6.5 – 7.0	--	0.1 – 0.2
Verde Grande (T)	6.2 – 8.2	12.4 – 16.1	--
Urucuia (T)	6.2 – 6.5	--	< 0.1 – 0.1
Abaeté (T)	7.9	--	0.3
Pandeiros (T)	7.2 – 7.6	< 1.0	--
Paracatu (T)	6.3	--	< 0.1 – 0.1
Paraopeba (T)	6.5 – 7.5	< 1.0 – 6.0	< 0.1 – 3.9

Table 6: Paraíba do Sul basin and tributaries (T), in Rio de Janeiro state in 1984 (Moreira-Nordemann, 1988)

River Name	pH	NO_3^- (mg/L)	NH_4^+ (mg/L)	SO_4^{2-} (mg/L)
Paraíba do Sul (SP)*	6.2 – 6.8	0.4 – 1.8	0.2 – 0.4	--
Jaguari (SP-T)*	6.4 – 7.1	0.3 – 1.6	0.2 – 0.3	--
Paraibuna (MG-T)†	6.7 – 7.2	--	0.3 – 1.6	4.0 – 5.0
Pomba (MG-T)†	6.8 – 7.4	--	0.1 – 0.3	< 1.0 – 1.5

Table 7: Tieté River and tributaries (T); minimum and maximum values obtained during 1981, 1983 and 1984 in monthly measurements **(**Moreira-Nordemann, 1988)

River Name	pH	NO_3^- (mg/L)	NH_4^+ (mg/L)
Tiete	6.2 – 7.5	0.1 – 4.5	0.1 – 8.2
Biritiba-Mirim (T)	6.3 – 6.4	0.4 – 0.6	0.04 – 0.14
Jundiai (T)	5.9 – 6.3	0.2	0.03 – 0.13
Taiacupeda (T)	6.6 – 6.9	0.1 – 5.8	0.13 – 1.08
Buquirivu-Guacu (T)	6.4 – 6.6	5.8 – 9.3	0.96 – 2.24
Represa Juqueiri (T)	6.4 – 7.0	0.3 – 1.9	0.06 – 1.86
Pinheiros (T)	6.6 – 6.8	0.4 – 1.5	4.95 – 15.84
Tamanduatei (T)	6.7 – 7.6	0.1 – 2.2	13.44 – 25.93
Jacare-Gaucu (T)	6.1 – 6.9	0.1 – 0.6	0.05 – 0.27
Jacare-Pepira	7.0 – 7.3	0.8 – 0.9	0.12 – 0.18
Piracicaba (T)	6.9 – 7.1	0.9 – 1.2	0.18 – 0.70
Cotia (T)	6.8 – 6.9	0.4 – 0.6	1.20 – 7.39
Sorocaba (T)	6.5 – 7.1	0.6 – 2.7	0.14 – 1.87

Table 8: Panapanema basin and tributaries (T), Sao Paulo state. Minimum and maximum mean values obtained for 1981, 1982 and 1983 in monthly measurements **(**Moreira-Nordemann, 1988)

River Name	**pH**	**NO_3^- (mg/L)**	**NH_4^+ (mg/L)**
Paranapanema	6.5 – 7.2	0.4 – 1.1	0.12 – 0.23
Taquari (T)	6.7 – 7.4	0.5 – 0.6	0.13 – 0.25
Pardo (T)	7.3 – 7.4	0.7 – 0.9	0.15 – 0.18
Itarare (T)	6.5 – 7.3	0.5 – 0.9	0.08 – 0.17

Table 9: Grande basin and tributaries, Sao Paulo state; minimum and maximum mean values obtained in 1981, 1982 and 1983 in monthly measurements.

River Name	**pH**	**NO_3^- (mg/L)**	**NH_4^+ (mg/L)**
Grande	6.8 – 7.2	0.3 – 0.35	0.01 – 0.04
Sapucai-Mirim	6.9 – 7.2	0.5 – 0.7	0.05 – 0.13
Pardo	6.6 – 7.1	0.5 – 0.8	0.03 – 0.17
Turvo	6.6 – 6.9	0.4 – 0.9	0.06 – 0.15
Preto	6.6 – 6.7	1.2 – 1.7	0.08 – 0.10

According to the authors of *Chapter 8: Acidification in Southeastern Brazil*, “The differences in nitrogen and sulfur concentrations observed in river waters of the southeastern region of Brazil cannot be explained by geological, pedological, or climatic factors. Higher NO_3^-, NH_4^+ and SO_4^{2-} contents were determined in rivers crossing urban and industrial areas, the same areas that also present a polluted atmosphere.”

These increases may be caused by “acid deposition.” Acid deposition is caused by pollution from motor vehicles, industrial process, and the burning of fossil fuels in power-stations, releasing sulfur dioxide, nitrogen oxide, and hydrocarbons. These pollutants react with water and sunlight to form dilute sulfuric acid, nitric acid, ammonium salts, and other mineral acids (Mayhew, 1997).

There are two types of “acid deposition” from the atmosphere: wet and dry (Fig. 2).

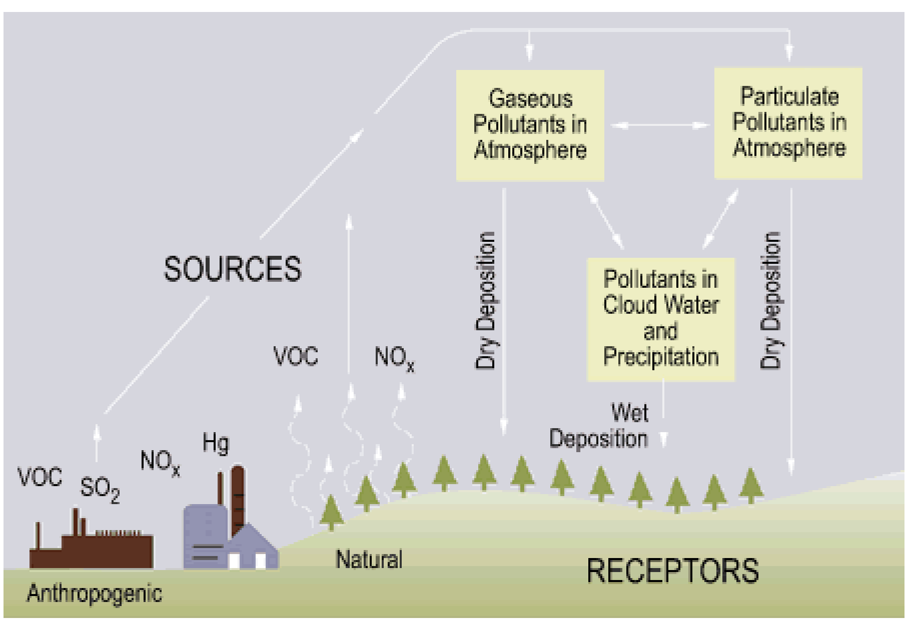


Figure 2: Acid deposition (EPA, 2002)

Wet deposition refers to acid rain, fog and snow. According to the Environmental Protection Agency, "the strength of the effects [of acidic water] depends on a variety of factors, including how acidic the water is, the chemistry and buffering capacity of the soils involved, and the types of fish, trees, and other living things that rely on the water."

Dry deposition refers to acidic gases and particles. Ions in the atmosphere fall down as dry particles. These particles are deposited onto buildings and other structures, or are washed from trees and other surfaces by rain. This runoff water exaggerates the acidity of acid rain (EPA, 2002).

Many organisms cannot tolerate high levels of acidity, and furthermore, many of the species that are able to tolerate the increased acidity are faced with diminished food supplies due to the increased acidic conditions. As acidity in a water system increases, the number and diversity of organisms decreases. Also, when acid rain flows through soils in a watershed, aluminum, which is toxic to fish, is released into the water system. At a pH of 5, most fish eggs cannot hatch (EPA, 2002). Table 10 details the harmful effects of acidification on aquatic biota.

Table 10: Effects of acidification on aquatic biota (Mills, 1984)

Physical and chemical changes	• Water transparency has increased, along with rates of hypolimnetic heating and thermo cline deepening • Concentrations of Mn, Na, Zn, H^+, $S_2O_4^-$, Al increased • Aluminum has been implicated as a major cause of fish mortality during lake acidification • $S_2O_4^-$ was reduced by bacteria to sulfide, followed by permanent sedimentation as FeS. Alkalinity, generated as byproduct of sulfate reduction, has neutralized approximately one-third of the hydrogen ion added to the lake. Therefore, a pH refuge has persisted below throughout the acidification, but the long-term trend has been for this refuge to become progressively more acidic, although temporally lagging behind the epilimnion.
Primary production and Invertebrates	• Primary production has increased in Lake 223 above pre-acidification levels • Phytoplankton species composition has changed with Chlorophyceae and Peridineae replacing Chrysophyceae • Appearance of hypolimnetic algal peak of Chlorella • Three members of the zooplankton community *Mysis relicta, Epischura lacustris, Diaptomus sicilis* disappeared as pH declined to 5.4, while *Daphnia catawba x schoedleri* appeared
Responses of Fish Populations to Acidification (pH lowered by 6.7 to 5.1)	• The fathead minnow population declined rapidly and almost disappeared when pH was 5.6. In addition, complete reproductive failure, rapid collapse of population were observed • The pearl dace population rapidly expanded to become the major minnow species when pH was 5.4. This was probably due to its greater tolerance to low pH by pearl dace than fathead minnow • White sucker (seen as relatively acid-tolerant species) showed no stress as the pH of the lake was lowered. Its individual fish growth remained consistently high. • The population of lake trout fish, which are relatively acid sensitive, decreased when pH was lowered from 6.7 to 5.4. However, its population did not decrease at the rate which was expected - it was much slower.

Because the water system of the Amazon is so large and complex, it is difficult to understand the true nature of the effects of acidity and acid deposition. From the data collected thus far, there seems to be a relationship between changes in the acidity of water and pollution. Further research is vital to the understanding of this relationship.

B. Mining

Mining has contributed to the amount of mercury found in the Amazon's rivers. It is estimated that 2000 tons of mercury have been dumped into the Amazon's rivers over the past century alone (Brown et al., 2002). It has been demonstrated that at times, the rate of mercury production is equivalent to the rate of gold production (Veiga).

The processes currently employed by miners utilize mercury to clean the gold. Often mercury is not properly disposed of, and instead is subsequently passed on to nature for disposal. Although mercury storied in the soil is in a harmless, organic form, mercury in the water is converted to methyl-mercury, which is one of the most poisonous substances known to man (Veiga).

Methyl-mercury filters down the river systems to communities down stream of the mining sites. Studies have proven that villagers in these areas suffer from the effects of mercury in their waters. Miners themselves have been victims of mercury poisoning as well.

In summary, mining requires a new cleaning method, one that either does not employ mercury at all, or makes clean up of the mercury used more effective. The trouble here will be convincing miner to switch to a new gold extraction method.

Another problem with mining is that it leaves large holes in the earth. As a result, mining sites are often covered by stagnant pools of water. Such pools are breeding grounds for mosquitoes, an in particular, mosquitoes which carry malaria (Brown et al., 2002). These mosquitoes are notably feared as they cause malaria in the local populations. Recently, malaria has become a widespread epidemic in Brazil. Nearly one-third of those diseased are less than 10 years old.

Fortunately, malaria is a simple disease to prevent. The simplest solution is to remove the stagnant pools of water. Miners should be required to cover any holes which are created during the mining process. This simple method is not performed by the miners although they are largely responsible for the increase in malaria cases in Brazil.

To improve mining and decrease its negative effects on the environment requires a fundamental change in the minds of miners. Incentives could be awarded to miners whose mining sites have been found to be compliant with certain standards established for environmental protection.

VI. Hydroelectric Power

A. Introduction

There are four main divisions of hydroelectric power plants: 1) micro-scale, 2) small-scale, 3) large-scale, 4) run-of-the-river, and 5) pumped storage.

Micro-scale plants are capable of producing one kilowatt to one megawatt of power. They are typically used for small, isolated villages in developing countries.

Small-scale plants are capable of producing up to twenty megawatts of power. These systems are relatively inexpensive to implement. They can be used in developing countries to provide electricity to rural areas.

Large-scale plants are the most efficient type of hydroelectric power plant. They are typically constructed by damning a river to form a lake. The largest hydroelectric power plant in the world[21] produces 12.6 GW of electricity, with an annual rate of 90 million MW hours. Large-scale plants take advantage of the potential energy of flowing water due to gravity to extrapolate energy.

Run-of-the-river hydroelectric plants work on the principle that the flow rate and elevation drops of the water are consistent enough that hydroelectric plants can be built directly in the river. The water passes through the plant without greatly changing the flow rate of the river. In many instances a dam is not required, and therefore the hydroelectric plant causes minimal environmental impact on its surroundings.

Pumped storage plants are used to provide peak power production during peak power usage times. During non-peak times, water is pumped back into an upper reservoir for peak time usage.

B. Power Production

Power production at given time is related to two factors: 1) flow volume, and 2) head. Head is a measure of the pressure of falling water. Rivers can be roughly divided into having either high or low[22] head. Hydroelectric production on rivers with less than two feet of vertical drop is unfeasible. The higher the head, the more efficient hydroelectric power production will be. Although high volume can compensate for low head, a more costly turbine to produce convert the energy to electricity will be necessary.

A simple formula for power is outlined below. It shows power dependent on gross head (H) and flow (F), as well as system efficiency (E), which typically ranges from 40-70%, and a constant (C) that is dependent on the particular unit system being used (U.S. Department of Energy, 2001).

$$P = H \times F \times E \times C$$

Equation 12

C. Effects

Hydroelectric Dams affect the river in the following ways:

1. Create water reservoirs/stagnant pools
    - Become breeding groups for malaria and other diseases
    - Higher water temperatures with little or no monthly variation
2. Increased flooding
3. Decreased residence time (fill with sediment)

[21] Itaipú hydroelectric power plant on the Paraná River
[22] Vertical drop < 10ft

4. Increased Eutrophication
5. Increased formation of methane gas
6. Corrosion of equipment
7. Decreased water quality downstream
8. Increased water temperature
9. Decreased water oxygen content
10. Increased siltation
11. Increased phosphorous and nitrogen content
12. Impact on fish populations
13. Energy transmission systems also have a negative impact on the environment

Damned rivers can be divided into four main segments: 1) an upstream segment, 2) the segment immediately behind the damn, 3) the segment immediately downstream of the damn, and 4) the segment downstream of the dam. The upstream segment of the river is largely unaffected by the dam. The segment of the river most affected by the dam is the portion directly downstream of the dam. In this section native fish population are the most severely affected, to the point that the population may be dominated by non-native species. With increasing distance from the dam, and with the influx of other rivers and streams, the affect of the dam becomes less severe. Correspondingly, native fish populations are more successful with this increasing distance (Brown et al, 2002). Fish populations which migrate each year upstream to spawn are particularly affected by damning. One simple solution for this is the construction of fish ladders, which provide pathways for fish to navigate past damns (Energy Matters, 1998).

Reservoirs have both positive and negative effects on the upstream and downstream environments due to the modification of the natural flow conditions. These effects include higher temperatures, with little to no variation in temperature throughout the course of a year; increased forest flooding, critical situation in reservoir filling (from the sediment dropped when the water slows in the reservoir), decreased residence time, increased eutrophication, increased gas formation, corrosion of equipment and a decline in the water quality downstream. One possible solution that would negate these negative effects is hydraulic equipment to reaerate reservoirs ("Water Quality Simulation in Reservoirs in the Amazon Basin: Preliminary Analysis" by Carlos Eduardo Morelli Tucci. From *Water Management of the Amazon Basin*).

D. Comparison

Table 11: Comparison of means of power generation in Brazil

Hydropower and Electricity	• Installed electric capacity of 68.8 million kilowatts, 87% hydropower (2000) • 342.3 billion kilowatt-hours generated in 2000, in 2000: 89% hydropower; in 1999: 91% hydropower • One of world's top hydropower producers • Brazil's small northern and larger southern electrical grids joined in January 1999 into one grid that serves 98% of the country	• See effects above (Part C)
Oil	• Second largest oil reserves in South America (after Venezuela) at 8.4 billion barrels • Production 1.6 million barrels per day in 2001 • Oil consumption almost 2.2 million barrels per day in 2001	• Combustion results in sulfur and nitrogen impurities, pollution and green house effect.

	• Imports from mostly Venezuela and Argentina	
Natural Gas	• Production and consumption rose steadily throughout the 1990's • Imports beginning in 1999 • Natural gas reserves as of January 2002 at 7.8 trillion cubic feet • Fifth largest in South America behind Venezuela, Argentina, Bolivia, and Peru	• More efficient and more economical than some coal and nuclear plants • "20% of total CO_2 emissions from fossil fuels in 1996 came from consuming and flaring natural gas. Natural gas emissions increased 26.9% from 1987 to 1996, the U.S. and Russia accounting for a whopping 42% of the world total" (International Energy Annual)
Coal	• Brazil's recoverable coal reserves are estimated approximately 13.2 billion short tons of lignite and sub-bituminous coal, giving it the largest coal reserves in Latin America • Due to high ash and sulfur content and low caloric value of domestic coal, Brazil imports a significant amount of cal • ~6.8 million short tons produced in 2000 • Consumption about 23.5 million short tons	• Emissions include sulfur oxides, nitrogen oxides, organic compounds, heavy metals, radioactive elements, and ash
Nuclear Energy	• Electronuclear • 2 operational nuclear plants, Angra-1 and Angra-2 • 1 under construction, Angra-3 • On hold, however electricity crisis may restart it, estimated 5 years to become operational • Nuclear Program came under Ministry of Defense rather than Ministry of Mines and Energy • Decrease in military funding meant delays in nuclear power plant construction • Government company, to assume responsibility for the plants	• Non-renewable energy • Final disposal of radioactive waste • In Angra-1: • -High levels of shutdowns • -Radiation spills
Ethanol and other biomass	• Sugar Cane Industry • Came as result of oil shock of 1973 • Generates more than 4,000 gigawatt hours annually to run its own refineries and distilleries • Has excess capacity of 200 MW • Produces between 3.4 and 3.7 billion gallons of ethanol for automobiles per year	• Could contribute to global warming • 1975: Brazilian National Alcohol Program created to regulate ethanol market and encourage production and use of fuel ethanol
Wind turbines (Energy Matters, 1998).	• Current total capacity of only 20MW • Further 25MW are to come on line in the north-eastern Ceara state, where trade winds are strong • Large numbers of turbines required to produce significant amounts of electricity • Larger impact on environment • Minimum wind speed • Small: 8 mi/hr	• Completely renewable source of energy • Safe

	• Large: 13 mi/hr • Large areas of land needed • Land can also be used for agriculture • High cost relative to production of energy • Only generate energy 25% of time	

VII. Conclusion

The water system of the Amazon Basin Rainforest will best be protected by imposing and enforcing stricter and more environmentally friendly mining and logging codes. Also important is an efficient use of power resources. It is necessary to use the hydroelectric dams in areas where they are likely to do the least damage, and to supply power nearby. Funding could be directed towards developing nuclear power plants that would be used to back up, and perhaps one day replace, hydroelectric power.

VIII. Sources

A. Works Cited

Sorooshian, S., Gao, X., Hsu, K, Maddox, R.A., Hong, Y., Gupta, H.V.
"Diurnal variability of tropical rainfall retrieved from combined GOES and TRMM satellite information." Journal of Climate May 1, 2002.

Tan, S. K., and Chiew, Y. M., *A new approach to rainfall recording and analysis*
Water Management of the Amazon Basin Ed. Braga, Benedite P. F., Jr., and Fernandez-Jauregui, Carlos A. UNESCO (1991): 35-44.

Molion, Luiz Carlos Baldicero "Climate variability and its effects on amazonian hyrdology" *Water Management of the Amazon Basin* Ed. Braga, Benedite P. F., Jr., and Fernandez-Jauregui, Carlos A. UNESCO (1991): 261-274.

Alsdorf-D.E.; Melack-J.M.; Dunne-T.; Mertes-L.A.K.; Hess-L.L.; Smith-L.C, 2000, Interferometric radar measurements of water level changes on the Amazon flood plain, Nature. 2000 MAR 09; 404(6774): 174-177

Callede, Jacques; Guyor, Pascal Kosuth Jean-Loup; and Guimaraes, Valdemar Santors, 2000 *Discharge determination by Acoustic Doppler Current Profilers (ADCP): a moving bottom error correction method an d its application on the River Amazon at Obidos,* : Hydrological Sciences 45(6): 911.

Cobby-D.M.; Mason-D.C.; Davenport-I.J, 2001, Image processing of airborne scanning laser altimetry data for improved river flood modelling, Journal-of-Photogrammetry-and-Remote-Sensing. 2001; 56(2): 121-13

H. Matsuyama *, J.A. Marengo, G.O. Obregon, C.A., Nobre, 2002, Spatial and temporal variabilities of rainfall in tropical South America as derived from Climate Prediction Center merged analysis of precipitation, International Journal of Climatology
22 (2): 175-195

Saliot, A et al., "Particulate Organic carbon, sterols, fatty acids and pigments in the Amazon River system", Biogeochemistry, Kluwer Academic Publishers, 2001, v53 p79-103

"Amazon River" Encyclopædia Britannica < http://www.search.eb.com/eb/article?eu=121415 > [Accessed September 30, 2002].

Molion, Luiz Carlos Baldicero "Climate variability and its effects on amazonian hyrdology" *Water Management of the Amazon Basin* Ed. Braga, Benedite P. F., Jr., and Fernandez-Jauregui, Carlos A. UNESCO (1991): 261-274.

Shaw, Robinson. Sea surface temperatures impact weather in Amazon basin. <http://www.enn.com/enn-news-archive/1999/12/122499/sstamazon_8414.asp>

Costa, Heil, Marcos, and Foley, Jonathan. "Trends in the Hydrologic Cycle of the Amazon Basin". Journal of Geophysical Research. Vol. 104 No. D12. 1999.

Engman, E. T. Remote sensing in hydrology / London : Chapman and Hall ; New York : Van Nostrand
Reinhold, 1991.

Marengo, J. A; Miller, J. R.; Russell, G. L.; Resenzwieg, C. E.; and Abramopoulos, F."Calculations of river-runoff in the GSS GCM: impact of a new land-surface parameterization and runnoff routing model on the hydrology of the Amazon River." Climate Dynamics 10 (1994) : 349-361

Eltahir, E. A. B., and Bras, R.L. "Precipitation Recycling in the Amazon Basin." Quarterly Journal of the Royal Meteorological Society 1994

Roche, M. A. Water and salt balances of the Bolivian Amazon. Ed. Benedite Braga, and Carlos Fernandez-Jauregui. 1991. 83-94.

Nobre, Carlos A. Possible climatic impacts of Amazonia Deforestation. Ed. Benedite Braga, and Carlos Fernandez-Jauregui. N.p.: n.p., 1991. 245-260.

Dickinson, Robert E. and Kennedy, Patrick, 1992, Impacts on regional climate of Amazon deforestation, Geophysical Research Letters 19 (19) P1947-1950

Lean, J., and P. R. Rowntree. "A GCM Simulation of the Impact of Amazonian Deforestation on Climate Using and Improved Canopy Representation." Quarterly Journal of the Royal Meteorological Society 1993:

Henderson-Sellers, A.; Dickinson, R. E., Durbudge, T. B., Kennedy, P. J., McGuffie, K., and Pitman, A. J., 1993, Tropical Deforestation: Modelling local- to regional-scale climate change, Journal of Gephysical Research Vol 98 No. D4 P7289-7315

"Oxbow lake" Encyclopædia Britannica <http://search.eb.com/eb/article?eu=59265> [Accessed November 24, 2002].

"Cumulonimbus Cluster (CB)" 2000 SAF/NWC/ZAMG/SCI/MTR/001 1: 10.142/204

"Albedo" Encyclopædia Britannica <http://search.eb.com/eb/article?eu=5466> [Accessed December 2, 2002].

Cosyn, Bart "Surface Roughness" Laboratory of Hydrology and Water Management, Ghent University < http://taoren.rug.ac.be/members/bart/paper/node26.html > [Accessed December 2, 2002].

"Albedo" *Encyclopædia Britannica* <http://search.eb.com/eb/article?eu=5466> [Accessed December 2, 2002].

Cosyn, Bart "Surface Roughness" Laboratory of Hydrology and Water Management, Ghent University < http://taoren.rug.ac.be/members/bart/paper/node26.html > [Accessed December 2, 2002].

"Cumulonimbus Cluster (CB)" 2000 SAF/NWC/ZAMG/SCI/MTR/001 1: 10.142/204

H. Matsuyama *, J.A. Marengo, G.O. Obregon, C.A., Nobre, 2002, Spatial and temporal variabilities of rainfall in tropical South America as derived from Climate Prediction Center merged analysis of precipitation, International Journal of Climatology 22 (2): 175-195

"Amazon River" Encyclopædia Britannica < http://www.search.eb.com/eb/article?eu=121415 > [Accessed September 30, 2002].

Acid Rain. U.S. Environmental Protection Agency. 28 Oct. 2002 <http://www.epa.gov/airmarkets/acidrain/index.html>.

Mills, Kenneth H. "Fish Population Responses to Experimental Acidification of a Small Ontario Lake." Early Biotic Responses to Advancing Lake Acidification . 1984.

L. M. Moreira-Nordemann, M. C. Forti, V. L. Di Lascio, C. M. do Espirito Santo and O. M. Danelon. "Chapter 8: Acidification in Southeastern Brazil." Acidification in Tropical Countries. Ed. Rafael Herrera, and Henning Rodhe. N.p.: John Wiley & Sons, 1988.

H. Rodhe, E. Cowling, I.E. Galbally, J. N. Galloway and R. Herrera. "Chapter 1: Acidification and Regional air Pollution in the Tropics ." Acidification in Tropical Countries. Ed. Rafael Herrera, and Henning Rodhe. N.p.: John Wiley & Sons, 1988.

Mayhew, Susan. "Acid Rain." A Dictionary of Geography. 20 Oct. 2002 <http://www.xrefer.com/entry.jsp?xrefid=608152&secid=.-&hh=1 >.

Alsdorf-D.E.; Melack-J.M.; Dunne-T.; Mertes-L.A.K.; Hess-L.L.; Smith-L.C, 2000, Interferometric radar measurements of water level changes on the Amazon flood plain, Nature. 2000 MAR 09; 404(6774): 174-177

Brown, Larry R. and Ford, Tim, 2002, Effects of flow on the fish communities of a regulated California river: Implications for managing native fishes, River Research and Applications

Cobby-D.M.; Mason-D.C.; Davenport-I.J, 2001, Image processing of airborne scanning laser altimetry data for improved river flood modelling, Journal-of-Photogrammetry-and-Remote-Sensing. 2001; 56(2): 121-13

Costa, Marcos Heil and Foley, Jonathan A., 1999, Trends in the hydrologic cycle of the Amazon Basin, Journal of Geophysical Research, 104: D12, P14,189-14,198.

Dickinson, Robert E. and Kennedy, Patrick, 1992, Impacts on regional climate of Amazon deforestation, Geophysical Research Letters 19 (19) P1947-1950

Goudey, Clifford A. et al., A Robotic Boat for Autonomous Fish Tracking, MTS Journal Vol 32, No. 1 p. 47-53

Greenberg, Harvery, 1995, EOS - Amazon Hydrological Models, EOS Amazon Project at the University of Washington http://boto.ocean.washington.edu/eos/hydro_data.html

Hauser, Rachel. "Fish in the Trees." NASA Earth Observatory (n.d.). 20 Oct. 2002 <http://earthobservatory.nasa.gov/Study/FishTrees/>.

Cheshire, Laura. "River Seasons." NASA Earth Observatory (n.d.). 20 Oct. 2002 <http://earthobservatory.nasa.gov:81/Study/RiverSeasons/>.

Lean, J. and Rowntree, P. R., 1993, A GCM simulation of the impact of Amazonian deforestation on climate using an improved capony representation, Quarterly Journal of the Royal Meteorological Society 119 pp 509-530

Henderson-Sellers, A.; Dickinson, R. E., Durbudge, T. B., Kennedy, P. J., McGuffie, K., and Pitman, A. J., 1993, Tropical Deforestation: Modelling local- to regional-scale climate change, Journal of Gephysical Research Vol 98 No. D4 P7289-7315

Lundberg, John, 2001, Freshwater Riches of the Amazon, Natural History

M Veiga and J Meech (University of British Columbia), 'Heuristic Approach to Mercury Poisoning in the Amazon'

Martin, Anthony et al., Tracking Aqautic Vertebrates in Dense Tropical Forest Using VHF Telemetry, MTS journal Vol 32, No. 1 p. 82-87

R.C. Willis, 'Mercury Rising', Today's Chemist at Work, March, 2001.

Rainforest Ecosystems, Animal Diversity, 2002, Encyclopedia of Biodiversity Vol 5, p 1-11

Sures, Bernd, 2001, The use of fish parasites as bioindicators of heavy metals in aquatic ecosystems, Aquatic Ecology 35: 245-255

The Relevance of the OECD Guidelines for Multinational Enterprises to the Mining Sector and the Promotion of Sustainable Development

A 'Paradise Lost' in the Colombian Amazon, Copyright 1996. The Light Party, http://www.lightparty.com/Misc/COCALEAF.html

SIVAM slide show, http://www.obt.inpe.br/mapsar/SIVAM/page_04.htm

Hydrolab: The best instruments and sensors in the Industry , http://www.hydrolab.com/Products.html

"Channel floodplain geomorphology along the Solimoes-Amazon River in Brazil.", Authors: Leal A. K. Mertes, Thomas Dunne, Luiz A. Martinelli., Originally published in *Geological Society of America Bulletin*, September 1996

"Exchanges of sediment between the flood plain and channel of the Amazon River in Brazil", Authors: Thomas Dunne, Leal A. K. Mertes, Robert H. Meade, Jefferey E. Richey, Bruce R. Fursberg. , Originally published in *Geological Society of America Bulletin*, April 1998

"Water Quality Simulation in Reservoirs in the Amazon Basin: Preliminary Analysis", Author: Carlos Eduardo Morelli Tucci., Originally published in *Water Management of the Amazon Basin*

Global Rainforest Mapping Study – Amazon, thttp://southport.jpl.nasa.gov/amazon/imagebrowser/jamms.html

"Surrogate Techniques for Suspended-Sediment Measurement" Authors: Daniel G. Wren, Roger A. Kuhnle, Originally published at *Turbidigy and Other Sediment Surrogates Workshop*, April 30-May2, 2002, Reno NV

International Energy Annual. U.S. Department of Energy. 23 Nov. 2002 <http://www.eia.doe.gov/emeu/iea/>.

"Brazil Hopes For Sweet Surge." Financial Times (2001). 23 Nov. 2002 <http://www.evworld.com/databases/shownews.cfm?pageid=news290601-06>.

"Oxbow lake" *Encyclopædia Britannica* <http://search.eb.com/eb/article?eu=59265> [Accessed November 24, 2002].

Rosenberg, Matt T. "Oxbow lakes" *About* < http://geography.about.com/library/weekly/aa010601a.htm> [Accessed November 24, 2002].

B. Additional Resources

Possible climatic impacts of amazonia deforestation
Authors: Nobre, Carlos A.
Source: Water Management of the Amazon Basin, (245-260)
Editors: Braga, Benedite P. F., Jr., and Fernandez-Jauregui, Carlos A.
Date: August 1991

Water and salt balances of the Bolivian Amazon
Authors: Roche, M. A., et al.
Source: Water Management of the Amazon Basin, (83-94)
Editors: Braga, Benedite P. F., Jr., and Fernandez-Jauregui, Carlos A.
Date: August 1991

A GCM simulation of the impact of Amazonian deforestation on climate using an improved capony representation
Authors: Lean, J. and Rowntree, P. R.
Source: Quarterly Journal of the Royal Meteorological Society 119 pp 509-530
Date: 1993

Precipitation recycling in the Amazon basin
Authors: Eltahir, E. A. B. and Bras, R. L.
Source: Quarterly Journal of the Royal Meteorological Society 120 P861-880
Date: 1994

Diurnal variability of tropical rainfall retrieved from combined GOES and TRMM satellite information
Authors: Sorooshian-S.; Gao-X.; Hsu-K.; Maddox-R.A.; Hong-Y.; Gupta-H.V.; Imam-B.
Source: Journal-of-Climate. 15(9): 983-1001
Date: May 1, 2002

EOS - Amazon Hydrological Models
Author: Greenberg, Harvery
Source: EOS Amazon Project at the University of Washington

Water and salt balances of the Bolivian Amazon
Authors: Roche, M. A., et al
Source: Water Management of the Amazon Basin, (83-94)
Editors: Braga, Benedite P. F., Jr., and Fernandez-Jauregui, Carlos A.
Date: August 1991

Shaw, Robinson, 1999, Sea surface temperatures impact weather in Amazon basin, http://www.enn.com/enn-news-archive/1999/12/122499/sstamazon_8414.asp.

Offl-line simulation of the Amazon water balance: a sensitivity study with implications for GSWP
Authors: Chapelon, N., Douville, H., Kosuth, P., Oki, T.
Source: Climate Dynamics 19: 141-154
Date: March 2, 2002

Trends in the hydrologic cycle of the Amazon Basin
Authors: Costa, Marcos Heil and Foley, Jonathan A.
Source: Journal of Geophysical Research, Vol. 104 No. D12, P14,189-14,198
Date: June 27, 1999

Seasonal cycle and interannual variability in the Amazon hydrologic cycle
Author: Zeng, Ning
Source: Journal of Geophysical Research, Vol 104 No. D8, P9097-9106
Date: April 27, 1999

Calculations of river-runoff in the GSS GCM: impact of a new land-surface parameterization and runoff routing model on the hydrology of the Amazon River
Authors: Marengo, J. A.; Miller, J. R.; Russell, G. L., Rosenzweig, C. E.; and Abramopoulos, F.
Source: Climate Dynamics Vol 10, P349-361
Date: 19994

Effects of flow on the fish communities of a regulated California river: implications for managing native fishes
Authors: Brown, Larry R. and Ford, Tim
Source: River Research and Applications
Date: May 15, 2002

Energy Matters
Team 20331
Thinkquest
Date: 1998

Hydroelectric Power
Authors: Leighton, Greg; Hitchins, Katy; Burrell, Greg; and Hays, Ross

Is a micro-hydroelectric system feasible for you?
U.S. Department of Energy
Date: September 2001

The hydroelectric power option in Brazil environmental, technological, and economic aspects
World Energy Council

"Amazon Region Requirements and SIVAM Capabilities" http://www.raytheon.com/products/sivam/ref_docs/requirements.pdf

"Raytheon Plays a Key Role in the Government of Brazil's System for the Vigilance of the Amazon (SIVAM)" http://www.raytheon.com/products/sivam/ref_docs/sivam_e1.pdf

SIVAM News http://www.raytheon.com/products/sivam/sivam_news.html

"Brazil's President Inaugurates Amazon Monitoring System " http://www.spacedaily.com/news/eo-02zb.html

"The Amazon Fortress" Margolis, Mac. Newsweek 2002 http://www.msnbc.com/news/823437.asp

"Brazil spies on Amazon loggers" BBC News July 25. 2002 http://news.bbc.co.uk/2/hi/americas/2151222.stm

Kowalski, B. J. "Brazil: Amazon snafu" World Press Review April 1996

"Raytheon Watch" J. Whitfield Larrabee & Associates http://www.gis.net/~larrabee/Brazil.htm

IX. Appendix

A. Rainfall Data

Figure 3: Water year rainfall map - 1985 (Greenberg, 1995)

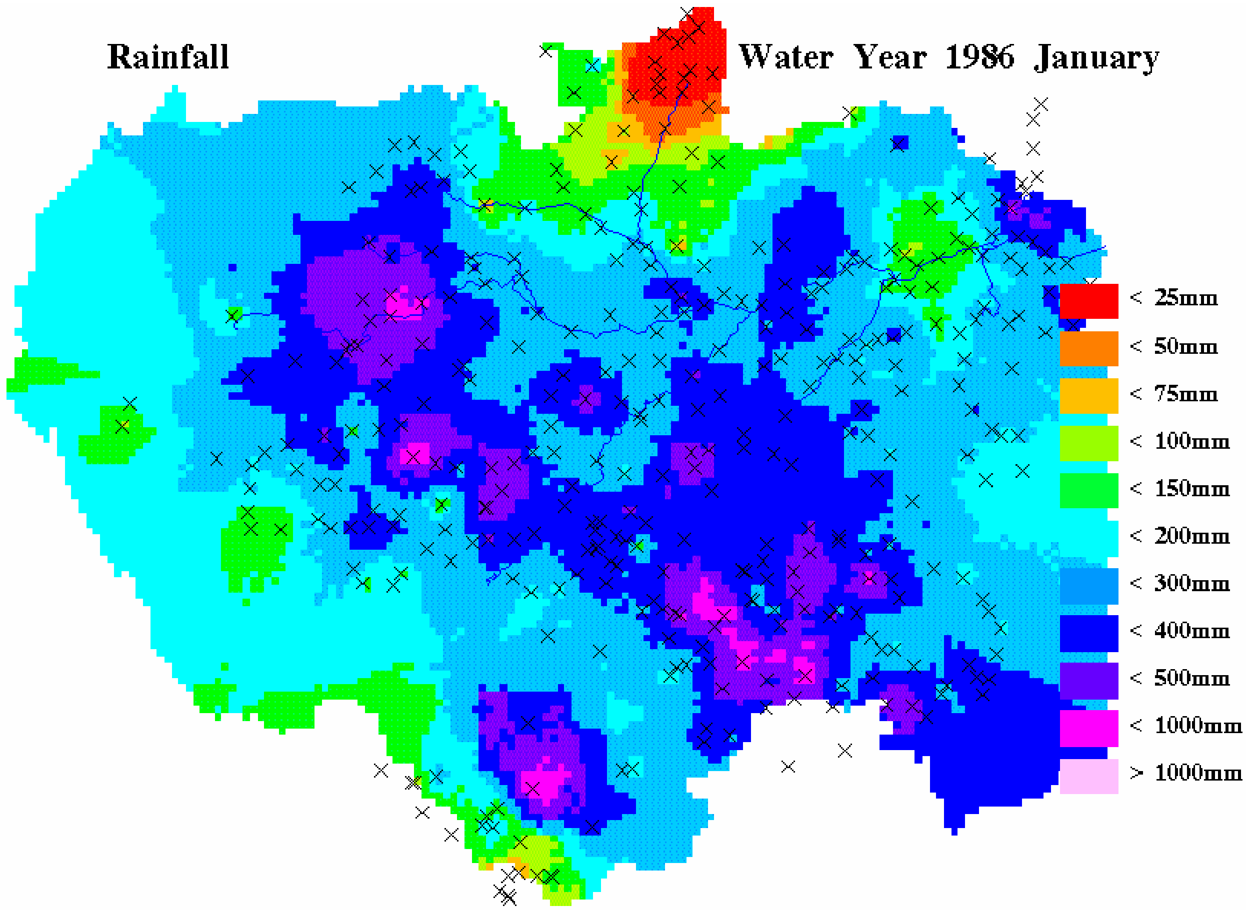


Table 12: Rainfall by region

Major Region	Subregion	Rainfall (mm)
Madre de Dios basin	Andean flank	2500-7000
	Plain	1800-2500
Beni River Basin	Average	1755
	Summit in andean part	800-1000
	Upper part of hot valleys (Yungas) in andean part	400
	Most protected zones - behind upper summiits of the Cordilleera	350-500
	Main part of andean basin	1720
	Plains	1650-2000
Mamoré andean basin	Average	1850
	Most semi-arid zone	480

	Foot of the andes	600
	Average in Rio Grande basin	750
	Oriental watersheds	3000
	Amazon plain	800
	Ichilo basin	3000
	Head of Madeira river	1900
	Toward north	800-1900
	Toward west	1000-4000
Itenez River basin	Average	1375
	South	900
	East	1800
	Northeast	1900
Upper Madeira basin	Average	1705

B. Definition of an 'A'

Rain 6 will:

1. Research and analyze data from previous papers (e.g. rainfall reports, chemical composition of water etc.) associated with the Amazon Basin's water ecosystems. Then, we will proceed to characterize these water systems which, among other tasks, will require us to consider the effects of deforestation and integrate information from various geographical regions within the Amazon Basin region.
2. Analyze the outflow, inflow and water storage mechanics of the Amazon water system as a whole, in terms of several variables such as evaporation, precipitation, transpiration, filtration, absorption etc. and develop a model based on what our research will yield in terms of these components of the water cycle.
3. Identify and devise ways to monitor the water chemistry and chemical composition of the sediments of rivers, lakes and other water systems in the Amazon Basin.
4. Examine the effects of seasonal variations, human development, and general environmental changes on the water ecosystem. We will also research the role of water on other systems of the rainforest.
5. Collaborate and communicate with other teams and define the way we will be interacting with them in topics that will require involvement by both (or more) groups. For example, the study of the diversity of water organisms will require our collaboration with the flora and fauna groups.

C. Progress as of November 8, 2002

The water group has spent the last two months reading articles about the state of the Amazon River, and in particular the water components of that system. We have looked into the overall water cycle, the aquatic fauna that inhabit the system, major pollutants which are affecting the system, and the affect of deforestation on the system among other topics.

In doing so, we have compiled a list of all the monitoring systems which we feel are needed to accurately characterize the water system on a continual basis. These monitoring systems will, where possible, take full advantage of recent developments in remote sensing techniques in order to minimize financial and labor costs and maximize functionality. There will also be land-based monitoring systems to take measurements on such parameters as rainfall and aquatic fauna populations. Often these land-based systems can be used to calibrate remote sensing systems. Where these land-based monitoring systems may be more accurate in monitoring specific parameters on a local scale, remote sensing systems allow for regional and continental scale monitoring.

Recently, we have also been to collaborate with all of the groups of the Mission 2006 class in order to formulate an overall preservation scheme for the Amazon River basin. As collaborate with these other groups, we will strongly advocate regulating deforestation and mining, as these two activities have the greatest overall affect on the water system of the Amazon River basin. In doing so, we will need to work with the economics group (#1) to engineer cost effective solutions. Our collaboration with the economic group will also be of particular importance in determining the feasibility of various preservation schemes and monitoring systems.

D. Project SIVAM

Introduction

Project SIVAM (System for the Vigilance of the Amazon) was conceived in 1990 by the Brazilian government as a means to monitor and determine the region's potential, limitations, and realities. In 1992 at the UN Conference on the Environment and Development in Rio de Janeiro, the project was announced publicly to the world. By 1997, Raytheon began work as the project's largest contractor after approval of the project by the Brazilian Senate. The other two major partners in the project are Fundação para Aplicações de Tecnologias Críticas (ATECH), a Brazilian Foundation focusing on the application of critical technology and its US subsidiary, Amazon Tech; and Embraer , a Brazilian aircraft manufacturer. Work on the project is expected to be completed within five years, by the end of 2002. The first operational product of the project, new satellite receiver / processing system to generate images of the region was available in June 1999. By June 2000, Raytheon delivered the first laboratory aircraft of the project to the Brazilian Air Force.

The four major categories of the project include:

- Environment
    - Deforestation monitoring
    - Forest fires monitoring
    - Flood monitoring
    - River pollution monitoring
    - Air pollution monitoring
- Regional planning and support to local communities
    - Support to zoning and land use actions
    - Flood prediction
    - Climatological data gathering
    - Weather forecast
    - Telecommunications improvement
    - Mapping
    - Support to prevention and control of diseases
- Law enforcement
- Air traffic

The technical infrastructure for the project will consist of both forty-six land and air-based stations. Air-based stations will include synthetic aperture radars, multispectral scanners, optical infrared sensors, high frequency direction finding equipment, and communications and non-communications exploitation gear. Much of this will be installed onto three remote sensing aircraft, modified versions of the Embraer ERJ-14. All of the data collected will then be funneled to one of three processing stations (Manuas, Porto Velho, and Belem) in Brazil. A general processing center will be installed in Brasilia.

Information generated by the surveillance systems of the project will be used for:

- Environmental protection

- Control of land occupation and usage
- Economical and ecological zoning
- Updating of maps
- Prevention and control of epidemics
- Protection of the indigenous populations
- Surveillance and control of the borders
- Monitoring of river navigation and forest fires
- Identification of illegal activities (gold mining, deforestation, drug production and smuggling)
- Air traffic control
- Surveillance of cooperative and non-cooperative aircraft
- Increase weather monitoring accuracy
- Improve the health of the Brazilian people

Controversy

Since the project was conceived in 1990, critics of the project have called it an extravagance and a toy of the military. Yet despite budget cuts, the project has survived.

The project has also been surrounded by cloud scandal. Rival bidders have accused one another of trying to bride Brazilian government officials. A 1996 World Press Review article in fact stated that "investigations have showed that [Raytheon] use bribery to get the contract." The major piece of evidence in the case seems to have come from a 1995 wiretap of Julio Cesar Gomez dos Santos, a special advisor to President Cardoso, which indicated that a Raytheon lobbyist may have bribed a Brazilian senator to gain backing for the SIVAM project. Brazil's president blocked a parliamentary investigation into this matter, and so that project has remained on course.

Other critics of the program feel that it is merely a way for gringos to spy of Brazil.

Environmentalists believe that the project's real goal is national security and not protection of the environment. In theory forestry officials, environmentalists, and tropical ecologists will be able to gain access to the data collected by the system. This however, supposes that such people will have the resources to analyze the data. For example, when the project was initially proposed, only a mere $5 million was appropriated for the National Amazon Research Institute in Manuas. By 2001 the budget had been cut to $500,000. According to Luiz Gylvan Meira Filho, science-policy chief for Brazil's Science and Technology Ministry, "SIVAM is not a tool for scientific research . . . It was created so the government can better carry out its job of protecting the Amazon region."

There is also some feeling that the law enforcement component of the project is doomed to fail as well without additional resources. The federal environmental authority is severely understaffed and is currently faced with a $20 million dollar shortfall this year. The army this year had to release 44,000 recruits and the air force had to ground its planes for weeks at a time this year due to a lack of funding. Defense experts say the radar will be a "toothless tiger," with the Brazilian military banned from shooting down suspect aircraft.

Evaluation - SIVAM's Problems

From what we have read up to this point, there seem to be some serious problems with project SIVAM.

The first problem with the program is the controversy that surrounds Raytheon and allegations of the company using bribery as a means of ensuring that it would be selected by the Brazilian government to execute the program. Rumors of bribery, from what we can tell have never been dispelled. The issue was tabled when the Brazilian president blocked a full investigation into the subject.

The second problem that we have found with SIVAM is the project's funding. Although the government seems eager to spend $1.4 billion to build and infrastructure with which to monitor the Amazon, there appears to be a serous lack of funding for analysis of any collected data. Agencies responsible for conducting any such analyses are understaffed and under funded. One article I read suggested funneling Brazilian college graduates into the project. However, the article added that the Brazilian university system is already taxed and therefore is not prepared to handle such a task. Furthermore, since the major Brazilian universities are not located in the Amazon, it seems unlikely that such a program will occur in the near future. Another article we read seemed to emphasize that analysis of the data is at this point largely theoretical, that is that if agencies had the funding and staff to perform such analysis, they would have access to the data. The fact, however, remains that these agencies do not have the resources to do so. One example of this is the National Amazon Research Institute, whose initial meager budget of $5 million has been cut to just $500,000. This lack of funding even seems to extend to the law enforcement component of the project. For example, last year the Brazilian army was forced to turn down 44,000 recruits due to budget constraints. Another example of this is the federal environmental authority, which is faced with a $20 million shortfall this year.

The third issue that we have found with the project is that there seems to be a degree of secrecy surrounding it. This may not be a problem. We were just curious as to why the world's major newspapers have given so little attention to such a massive project. The Washington Post for example, has only published two articles on the project ever; the New York Times and LA Times have each only published three articles. The majority of the press attention on the project surrounds the Embraer planes. The articles however, are largely found in national security and defense industry journals. Even the bribery scandal received very little press. In fact, the issue never reached the Washington Post or New York Times.

Evaluation - Implication of SIVAM for Mission 2006

Having read about a serious lack of resources with which to analyze all the data being collected, there does seem to be something that the Mission 2006 class could offer the SIVAM project, manpower to analyze the data. Raytheon in fact, already appears to be committed to training people to develop applications for analyzing the collected data. The other thing the class could offer the SIVAM project is funding or links between organizations willing to fund such projects and organizations capable of analyzing data.

Our suggestion to those people in the class who have volunteered to meet with representatives from Raytheon is first to get more information about the project. Since there has been little press about the issue and the project's main website is only available in Portuguese, details of the project are very limited. Furthermore, there seems to be some discrepancy of the details of the project. For example, we have seen the number of land-based monitoring stations vary from a low of 46 to a high of 900+. The number of planes involved in the project seems to have an equally variable number. Specific to the water group, we would like to get information on what the SIVAM project will be capable of in terms of monitoring river pollution, flow volumes, evapotranspiration, aquatic biota, sediment flow, and rainfall.

Secondly, we would ask the Raytheon representatives as to what an outside group like our class could contribute to the project if not offer our assistance to them. The problem here is that Raytheon is not ultimately in charge of the project. That rests with the Brazilian government, but perhaps Raytheon would be able to link our class with representatives from the government.

In summary, we think that the SIVAM project has great potential. Our fear is that this potential is being wasted with a lack of funding for analysis of the data. This does however, leave some opening for our class to make a contribution or more likely propose a contribution to SIVAM. In terms of the options Kip listed on the board on Friday November 1 (ignore, capitulate, etc.) it seems like we should move to cooperate with the SIVAM project. We should not however, limit ourselves to cooperate with this one project. There are many, many large-scale Amazon monitoring projects like this one, which we could potentially work with. Where this project does not appear to make much use of remote satellites for data collection, other projects offer that capability.

E. Budget

Table 13: Measuring Devices

Device	Cost (C)	Quantity (Q)	Total (C×Q)
Ground Monitoring Stations along River @ 100 mi			**$345,000.00**
Rain gauge	$150.00	150	$22,500.00
Lysimeter	$100.00	150	$15,000.00
pH / ion concentration meter	$1000.00	150	$150,000.00
Thermometer	$50.00	150	$7,500.00
Flow rate	$500.00	150	$75,000.00
Quanta-G water quality instrument			
Soil hydraulic conductivity measuring system	**$500**	**150**	**$75,000.00**
Satellites			**$ 0.00**
JERS-1, TRMM, TMI	$0.00	1	$ 0.00
GOES, SSM/I, LEOS	$0.00	1	$ 0.00
Computer	**$2,000**	**10**	**$20,000.00**
Robotic fish monitoring kayak	**$8,000.00**	**30**	**$240,000.00**
VHF telemetry monitoring system	**$1,000,000.00**	**12**	**$12,000,000.00**
Digital optical sediment monitoring system	**$0.00**	**1**	**$ 0.00**
Labor / yr			**$2,340,000.00**
Scientists	$75,000.00	12	$900,000.00
Support staff	$40,000.00	24	$960,000.00
Interns	$20,000.00	24	$480,000.00
Maintenance			**$2,000,000.00**
Boat for 10 people, 60ft	$2,000,000.00	1	$2,000,000.00
Small-scale hydroelectric power plant	**$5,000.00**	**10**	**$50,000.00**
Total			**$16,995,000.00**

Table 11: Solutions

Solution	Cost
Small-scale hydroelectric power plant	$5,000.00