Challenges and Opportunities for Conservation, Agricultural Production, and Social Inclusion in the Cerrado Biome

An assessment developed for the Climate and Land Use Alliance
by CEA Consulting

Appendix B: Water and Climate Change in the Cerrado

August 2016

Water and Climate Change in the Cerrado

Climate change, driven by both increasing concentrations of greenhouse gases in the atmosphere (global) and by changes in vegetation cover (local), has the ability to significantly alter a range of important conditions that underpin the Cerrado's ecological, social, and economic value. One of those important conditions is the biome's hydrological cycle. Changes to water availability and distribution can affect every aspect and function of the biome's landscape.

Overview of water in the Cerrado

With roughly an eighth of the world's fresh water supply, Brazil is sometimes called "the Saudi Arabia of water."[1] However, the common perception of Brazil's water security is easily distorted by the Amazon basin, which holds 75 percent of the country's water but only 4 percent of its human population. The Amazon's abundant water supply is far from the population and economic centers in the east and south of Brazil.[2] It is the Cerrado biome, far more than the Amazon, which plays a key role in distributing water resources throughout the country. Because the Cerrado is a central plateau, rainwater falling in its highlands runs off in all directions, a phenomenon called the "umbrella effect,"[3] and feeds major river ways across South America. Nearly all of Brazil's major river systems (10 out of 12) have portions that flow through the Cerrado. Three major rivers, the Tocantins, São Francisco and Paraná, have their headwaters in the Cerrado.[4,5] As a result, the Cerrado is widely considered "the cradle of Brazil's water" or "the large water tank of Brazil". The implications of water management in the Cerrado reach far beyond the biome.[6]

Waters originating in the Cerrado support agriculture, downstream cities and municipalities, and energy generated by hydropower. The São Francisco is a particularly important for human use, supplying water to 128 municipalities.[7] The Paraná, São Francisco and Tocantins river basins are each important for hydropower production. Because hydropower provides 80 percent of Brazil's electricity, the energy sector is vulnerable to water supply shocks, and droughts can cause spikes in electricity prices.

Water management in Brazil

Prior to 1997, an ad hoc water management system in Brazil was centralized, inefficient, and favored certain sectors of the economy, such as hydropower. Like much of the rest of the world during that time, Brazil's water management approach emphasized infrastructure- and technology-based solutions. In the face of increasing water demand and emerging paradigms of management, in 1997, Brazil passed the National Water Resources Policy to reform water management. The reform was designed to

---

[1] Simon Romero, "Taps Start to Run Dry in Brazil's Largest City," *New York Times*, Feb 16, 2015.
[2] Nathan L. Engle and Maria Carmen Lemos, "Unpacking governance: Building adaptive capacity to climate change of river basins in Brazil," *Global Environmental Change*, 2009.
[3] Jorge Enoch, "Situation and prospects for the Cerrado Waters," 2011.
[4] *Ibid.*
[5] Paulo Tarso Sanches Oliveira, "Water Balance and soil erosion in the Brazilian Cerrado," University of São Paulo, 2014.
[6] Enoch, 2011.
[7] Agência Nacional de Águas (ANA), *Atlas Brasil: abastecimento urbano de água, panorama nacional*, (Brasília, 2010).

increase integration, decentralize management and decision making to the river basin level, value water as an economic good, increase participation of stakeholders, and prioritize water for consumption by humans and livestock in the event of shortage. The law established the requirement of water resource plans, classified water bodies, created water use permits and pricing systems, and instituted a resources information system. One major innovation of the reform was that it encouraged the creation of tri-party river basin committees and consortia comprised of state and federal government, water users, and civil society organizations. These councils make decisions about water allocation and project development and provide a forum for conflict resolution. The strength and track record of these councils varies considerably by local basin conditions, council institutional structure, and state policy framework.[8]

Local land cover and hydrological flows

There are two primary counteracting and independent relationships between changes in land cover and hydrological flows. Reduction in vegetation cover (i.e., conversion of natural vegetation to cropland or pasture) leads to increased discharge into waterways because less water is used through evapotranspiration. At the same time, losses in vegetation can lead to decreased rainfall at a regional level because less water vapor is expelled into the atmosphere through evapotranspiration. Additionally, the removal of roots and soils, which act as a sponge for water, can reduce water flows from perennial to intermittent systems and can threaten water springs.

Increased discharge: River discharge is the difference between water input into the watershed from precipitation and water export via evapotranspiration through vegetation. Loss of vegetation leads to higher surface albedo, lower surface aerodynamic roughness, smaller leaf area, and shallower root depth, all of which contribute to reduced evapotranspiration and, therefore, increased discharge. These changes increase river flows during wet seasons but decrease local water availability during dry seasons.[9] A 2013 analysis indicates that historical land cover changes in the Brazilian Cerrado have caused significant decreases in evapotranspiration, “leading to a three-fold increase in discharge in small watersheds” and “a nearly 25% increase in large river basins like the Tocantins-Araguaia.”[10,11] While increased discharge into waterways could be a positive change for hydropower generation, municipal water use, and even irrigation, it could also lead to flooding during the wet season.

Regional precipitation patterns: There is a mounting body of evidence that rainfall patterns are maintained, in part, by forests themselves. Several recent academic studies conducted in Brazil provide evidence that increasing deforestation can decrease rainfall and, as a result, decrease agricultural yields, decrease hydropower generation, and catalyze landscape level changes in vegetation type. While most of the studies described below were conducted outside of the Cerrado, there is certainly reason to believe that the dynamics would be similar inside of the Cerrado biome. That said, there is a need for more focused research on these topics inside of the Cerrado.

---

[8] Engle and Lemos, 2009.

[9] Marcos Heil Costa et al., “Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia,” *Journal of Hydrology* 283 (2003), 206-17.

[10] M. Macedo et al., “Hydrological impacts of land-use change and agricultural policy in the Brazilian Cerrado,” (Paper presented at a Meeting of the American Geophysical Union, Fall 2013).

[11] Costa et al., 2003.

- A 2016 study found that Matopiba cropland agriculture roughly doubled in area 2003-2013, with most of the new cropland coming from previously intact vegetation. In 2013, cropland areas evapotranspirated 3% less water than if the land cover had been in native vegetation, with changes especially pronounced in the dry season and in single cropping systems (as compared to double cropping). Though the exact effects on rainfall are unknown, this may have led to an equivalent decrease in rain, and a delayed onset of the rainy season needed for double cropping.[12]
- In Rondônia (located in the Amazon biome), over 25 years of data from field stations indicate that inside of large deforested areas, the onset of the rainy season has shifted 11 days on average (and up to 18 days) later in the season. For stations not in deforested areas, the onset of the rainy season has not shifted significantly.[13]
- A study published in 2004 looking at the relationship between deforestation and precipitation in the Atlantic Forest found a lower number of rain days (less frequent rain) in areas that were deforested between 1962 and 1992, although the total amount of rainfall did not change. The degree of forest fragmentation also influenced frequency of precipitation, with patchier forests experiencing fewer rain days than larger blocks of contiguous forest.[14] These results suggest a shift towards more extreme weather events, with rainfall concentrated on fewer days.
- A 2013 study modeling the effects of deforestation on hydropower generation found that increased rates of deforestation lead to increased discharge into rivers (a good thing for hydropower). However, when regional-level decreases in rainfall as a result of deforestation were taken into consideration, the net river discharge decreased. Under a business-as-usual scenario for forest loss for 2050 (40%) in the Xingu Basin (located in the Cerrado and Amazon biomes), the study projected hydropower generation at the Belo Monte hydropower complex (located in the Amazon) to decline to only 25 percent of maximum plant output and 60 percent of the industry's own projections.[15]
- Agricultural expansion into areas of native vegetation could introduce climate feedbacks that would reduce precipitation and, therefore, reduce agricultural productivity, making agricultural expansion self-defeating. A 2013 study of pasture expansion in the Amazon found that the resulting decreases in rainfall reduced pasture yields to a point where cattle ranching became unviable in regions that it occupies today such as eastern Para and northern Maranhão.[16]
- Land cover change can also have regionally significant climate impacts. Two 2010 papers show that deforestation in the Cerrado may decrease precipitation in the 'arc of deforestation' in the south and eastern portion of the Amazon due to decreased evapotranspiration from the

[12] Stephanie Spera et al., "Land-use change affects water recycling in Brazil's last agricultural frontier," *Global Change Biology*, 2016.
[13] Nathalie Butt et al., "Evidence that deforestation affects the onset of the rainy season in Rondonia, Brazil," 2010.
[14] Thomas J. Webb et al., "Forest cover-rainfall relationships in a biodiversity hotspot: the Atlantic Forest of Brazil," *Ecological Applications* 15, no. 6 (2004), 1968-1983.
[15] Claudia M. Stickler et al., "Dependence of hydropower energy generation on forests in the Amazon Basin at local and regional scales," PNAS 110, no. 23 (2013).
[16] Leydimere J. C. Oliveira et al., "Large-scale expansion of agriculture in Amazonia may be a no-win scenario," 2013.

Cerrado.[17,18] Specifically, models suggest that deforestation in the Cerrado can reduce rainfall in the south and southeastern part of the Amazon during the transition months between the wet and dry seasons (transition months are September, October, and November), in effect lengthening the dry season in the arc of deforestation from 5 months to 6 months. Because the vegetation species in this area are very sensitive to small changes in moisture, this shift could be enough in some areas to cause a regime change in natural vegetation to a state more similar to a seasonal forest climate than a rainforest.[19]

The role of roots and soils: Cerrado soils are rich in clay, which makes them sponge-like in their ability to retain water. The upper soil layers lose moisture in the dry season, but several meters below the surface, the soils remain moist throughout the year. The deep and extensive root systems of Cerrado vegetation draw water from those moist layers and bring it to the surface, increasing the land's water retention and surface level moisture, qualities that can be very beneficial to agriculture in dry landscapes. Retention of moisture in roots and soils reduces overall runoff, while also making the runoff more consistent throughout the year (i.e., supporting the perennial nature of the waterways).[20] Roots and soils also play a particularly important role in evapotranspiration in the Cerrado because so much of its biomass is below-ground. Once land is converted from natural vegetation to pasture or cropland, the root system's ability to support evapotranspiration slowly diminishes over time. Retaining water in the Cerrado's soils through natural vegetation cover may also be critical to maintaining the springs that form the headwaters of many important rivers originating in the Cerrado. 2014 was the first year that the water springs feeding the headwaters of the São Francisco River ran dry. This may have been the result of regional land use change that reduced the soil moisture that feeds these springs. One researcher has suggested that in order to ensure the future integrity of the São Francisco River, 48% of current Cerrado vegetation must remain intact.[21]

Mounting scientific evidence along with anecdotal observations has led to a growing concern among a range of stakeholders in Brazil that the Cerrado biome is vulnerable to water stress and could have major repercussions for the country's water supply. Global and local climate change, increasing water demand, unsustainable land management and/or natural habitat conversion could each create the conditions for an insecure water future in the Cerrado. The combination of these factors could lead to great water supply shocks in Brazil. There may be thresholds for the removal of intact natural vegetation after which regime shifts in the hydrology and vegetation of the Cerrado take place. It is also possible that those thresholds have already been passed, at least in the southern part of the biome. Unfortunately, the lack of historical hydrology and climate data from the time before the largest portion of Cerrado deforestation (which has already occurred) makes it difficult to identify these thresholds. It is

[17] Ana Cláudia Mendes Malhado, Gabrielle Ferreira Pires, and Marcos Heil Costa, "Cerrado Conservation is Essential to Protect the Amazon Rainforest," *Ambio* 39, no. 8 (2010), 580-84.
[18] Marcos Heil Costa and Gabrielle Ferreira Pires, "Effects of Amazon and Central Brazil deforestation scenarios on the duration of the dry season in the arc of deforestation," *International Journal of Climatology* 30, no. 13 (2010).
[19] Ibid.
[20] Interview by *Valor Economico* with Mercedes Bustamante.
[21] Ibid.

clear that the Cerrado is hydrologically fragile and that the risks to water supply disruptions are serious. Preserving remaining natural vegetation could be one of the most important variables for ensuring sustainable water supply, especially in the context of a changing global and regional climate.

Overview of climate change in the Cerrado

During this century, both globally and locally-driven climate change will affect virtually every aspect of the Cerrado, including: local and regional temperature and atmospheric CO_2 concentrations, weather and precipitation patterns, the water cycle, land cover and vegetation type, fire prevalence, species abundance and range, and crop productivity, as well as flooding, drought, and hydropower production. The local climate change driven by deforestation can have an amplifying effect on the warming and drying trends caused by global climate change. However, the converse is also true. Efforts to preserve natural vegetation across the landscape can have a mitigating effect on global climate change impacts. Vegetation cover can counteract some of the warming and drying shifts that will be brought by global climate change, and can also moderate the effects. For example, if precipitation falls as a result of global climate change, abundant land cover can help keep soils moist and runoff into waterways steady.

Global climate change likely to increase temperature and decrease rainfall in the Cerrado

One of the more intuitive impacts of global climate change on the Cerrado will be a likely increase in regional temperature. A Brazilian Panel on Climate Change (PBMC) study released in 2013 found that the midwestern and northeastern regions of Brazil (largely overlapping with the Cerrado) are projected to be the most affected by global climate change. These studies, developed by INPE and Embrapa, suggest that temperatures will increase by between 1 degree C and 5.8 degrees C in the midwest by 2070, creating a more pronounced dry season (drier and warmer). On a national scale, temperature is likely to increase by 1 degree C by 2040, but by 2070, increases are projected to be between 3 and 3.5 degrees C. By 2100 temperature increases are likely to have increased from today's levels by 5 to 5.5 degrees C, or more.[22]

Most global climate models predict that greenhouse gas accumulation and associated increases in the radiative forcing of the atmosphere are likely to cause total precipitation reductions of more than 20 percent in the Cerrado by the end of this century during the already drier months of June-July-August.[23] The United Nations Intergovernmental Panel on Climate Change (IPCC) estimates that northeastern Brazil, which has some overlap with Cerrado area, will be hardest hit by climate change.[24] The PBMC 2013 report notes that temperature and precipitation changes caused by climate change are projected to reduce river flows in the midwest of Brazil from 2017-2100. Streamflow in eastern Amazonia is projected to decrease by up to 20 percent (the report did not provide figures for the Amazon as a whole,

[22] "First National Assessment Report (RAN1)," Brazil Panel on Climate Change (PBMC), September 8, 2013.
[23] Yadvinder Malhi et al., "Climate Change, Deforestation, and the Fate of the Amazon," *Science* 319, no. 5860 (2008), 169-72.
[24] Bryson Bates et al., "Climate Change and Water: IPCC Technical Paper VI," *Intergovernmental Panel on Climate Change*, 2008.

or for other biomes).[25] Groundwater recharge in northeastern Brazil is estimated to decrease by more than 70 percent by the 2050s.[26]

The relationship between local land cover and local climate

A 2001 study looked at the direct local climate effects of conversion from natural vegetation to pasture and cropland in Brazil. It found that converting natural vegetation to a (non-sugarcane) crop and pasture mosaic has an average local warming effect of 1.55 degrees C. Converting natural vegetation to sugarcane also has a warming effect, although the effect is less pronounced.[27]

Biodiversity

Climate change in the Cerrado will directly affect both flora and fauna habitat suitability and species range. Several climate models analyze various groups of flora and fauna, resulting in a spectrum of predictions.

- One global review found that mid-range climate change projections would lead to the extinction of 48 to 56 percent of woody plant species in the Cerrado by 2050. The same study found that between 18 to 35 percent of all widely distributed Cerrado species (including both flora and fauna) were likely to become extinct through a range of climate scenarios by 2050. The Cerrado's plant species may be particularly hard-hit due to their climatic sensitivity and limited ability to rapidly adapt their range. On average, climate change models predict extinction rates of 38 to 57 percent for the Cerrado's plant species.[28]
- A similar study found that for between 91 and 123 out of 162 tree species included in the study, potential distributional ranges in the Cerrado may decline by more than 90 percent, especially in the south and east.[29]
- A 2009 study indicates that bird species in the Cerrado will experience an average geographical displacement of 200 km to the southeast. Further predictions show that the geographical distribution of a collection of seven forest-dependent bird species will retract from 41 to 80 percent by 2100.[30]

Agricultural productivity

Crop productivity is likely to be seriously affected by the temperature and precipitation changes driven by both global and local climate change. A recent study conducted by Embrapa Brazil suggests that that, under certain climate change scenarios, the area of land in Brazil suitable for soy production may decrease by up to 39 percent by 2040. Furthermore, the likelihood of crop failure due to climate change is likely to become quite stark. This risk will affect growers' abilities to access credit to finance farm

---

[25] "First National Assessment Report (RAN1)," Brazil Panel on Climate Change (PBMC), September 8, 2013.
[26] Bates *et al.,* 2008.
[27] Scott R. Loarie et al., "Direct impacts on local climate of sugar-cane expansion in Brazil," *Nature Climate Change* 1 (2011), 105-109.
[28] Chris Thomas et al., "Extinction risk from climate change," *Nature* 427 (2004), 145-8.
[29] Marinez Ferreira de Siqueira and Andrew Townsend Peterson, "Consequences of global climate change for geographic distributions of cerrado tree species," *Biota Neotropica* 3, no. 2 (2003).
[30] M.A. Marini et al., "Predicted Climate-Driven Bird Distribution Changes and Forecasted Conservation Conflicts in a Neotropical Savanna," *Conservation Biology* 23, no. 6 (2009), 1558-67.

operations; risk of > 20% of crop loss are deemed "high risk," a threshold above which many financial institutions will withhold financing. Under the worst emissions scenario modeled by Embrapa, 99 percent of southern Brazil would be considered high risk for soybeans in 2040.[31] Studies using more conservative climate change projections still found direct impacts on crop yield. A 2008 study examining projected crop productivity in Brazil through 2030 found that temperature increases of 0.5 to 1.5 degrees C and precipitation decreases may decrease soybean productivity by ~4%, cassava, maize, and rice by ~5%, and wheat by > 6%.[32]

Decreased crop productivity also has the knock-on effect of requiring more inputs, and crucially, more land in order to achieve the same yields and at higher costs. Increasing dry season length can also decrease farmers' ability to double-crop during the wet season, significantly harming yields. Formerly unusual dry spells during the wet season can also have disastrous effects on crop yields. For example, anecdotally, a 10-day dry period during the wet season does not significantly impact soy yields, but a 15 day dry period can result in roughly a 20 percent reduction in crop yield.

Studies examining the impacts of climate change on silviculture have shown that the likely increased frequency and severity of droughts, driven by both global and local climate change, can result in reduced productivity, forcing expansion onto less suitable lands.[33]

Hydropower energy generation

As mentioned above, 70% of Brazil's energy is generated by hydropower. This feature of the economy is also vulnerable to the impacts of climate change on hydrological cycles, including the impacts of climate change driven by deforestation and land use change in Brazil. In 2001, a combination of increasing energy demand and severe drought caused a virtual breakdown of hydroelectricity and contributed to a reduction in national GDP figures.[34]

---

[31] "Área de cultivo de soja no Brasil pode diminuir 39% até 2040," *Observatório do Clima*, accessed September 2015, http://www.observatoriodoclima.eco.br/area-de-cultivo-de-soja-no-brasil-pode-diminuir-39-ate-2040/.
[32] David B. Lobell et al., "Prioritizing Climate Change Adaptation Needs for Food Security in 2030," *Science* 319, no. 5863 (2008).
[33] Phillip M. Fearnside, "Plantation forestry in Brazil: the potential impacts of climatic change," *Biomass and Bioenergy* 16, no. 2 (1999).
[34] Bates et al., 2008.