Sediment management in dams in the Andes

Vicente Tinoco
vicente.tinoco@berkeley.edu

The Andes Mountains, which run the length of South America, provide the countries with rivers with steep slopes and high discharges (Fig 1.), resulting in many potential sites for dam construction. Colombia, Ecuador, Peru, and Bolivia aim to increase their hydropower generation in 300% by 2030. Particularly in the Amazon Basin, on the eastern side of the Andes, recent publications have reported that 400 new dams for hydropower projects are planned, from which 150 dams are in the Andean Rivers (Finner and Jenkins, 2012; Little, 2013). However, hydropower is not the only objective for dams or reservoirs in these Andean countries. The climate conditions and water resources are different along them. In late 2016, citizens of La Paz, Bolivia experienced water rationing because of a drought. Peru has a high need of irrigation in the watersheds that drain to the Pacific. In 2017, there was large floods in Peru, Ecuador, and Colombia, due to an extreme rainfall event, denominated Niño Costero. Hence, many dams are also built for irrigation, drinking water supply, or flood control.

During five weeks, between June and July, 2017, I visited several organizations, institutions, universities, rivers, and dams in Colombia, Ecuador, Peru, and Bolivia, with the purpose of learning about the landscape geomorphology, built dam infrastructure, environmental concerns, as well as each country's plan, challenges, and problems for water storage and water use.

The Andes Mountains are a continental divide between watersheds that drains to the Amazon and to the Pacific in those countries. Tributaries to the Amazon River constitutes the largest basins in Ecuador, Peru, and Bolivia. In Colombia, the largest basin, is the Magdalena River, which drains to the Caribbean Sea. Annual rainfall in the Amazon subwatersheds in Colombia, Ecuador, and Northern Peru is among the highest in the world, exceeding 5,000 mm, while the annual rainfall in the Andean Amazon in Bolivia is about 1,500 mm. The annual rainfall in the watersheds that drains to the Pacific significantly changes from the areas nearby the Equatorial Line to the South. In Choco, Colombia the annual rainfall is 13,000 mm, while in Lima, Peru only rains 50 mm per year, and in the Arica region does not rain at all. In the Altiplano, inner semi-arid land in Bolivia and Southern Peru, where the drainage basins discharges into the Titicaca and Poopó Lakes, the annual rainfall is about 300 mm.

In Peru, 97.5 % of the total surface water resources of the country are in the Amazon Basin, 2% are in the watersheds that drains to the Pacific, and 0.5 % in the basins to Titicaca Lake. On the other hand, 65% of Peru’s inhabitants live in the basins that drain to the Pacific. A large percentage of the 700 built dams in Peru are for irrigation.

In Colombia, Madgalena and Cauca Basins generate about 70% of the country's hydropower production. In addition, those watersheds produce the 85% of the GDP and 65% of the Colombian population lives in those watersheds. (UPME and PUJ, 2015)

Ecuador has more than 2,265 streams and rivers in total in both drainage basins, Pacific and Amazon (International Rivers, 2017). During the last ten years, the country aimed to maximize its hydropower generation by building 10 out of 13 initially planned large projects. It had the purpose that hydropower became the 90% of the Ecuadorian electric source. In 2006, hydropower represented 46% of the electric source, thermoelectric was 53%, and 1% was generated by other renewable sources. Dam developing and high oil prices share common times in Ecuador. However, these money budget was not owned by the Ecuadorian

Government at the recent constructions times, rather it was part of a loan from Chinese Banks. Between 2004 to 2014, Chinese Ex-Im bank loaned US$ 8.4 billion for Energy development. (Gransow, 2015). Those loans consist on selling the oil in advance, or commonly named loans-for-oil (Escribano, 2013). There are 114 additional hydropower projects planned in Ecuador. (ARCE, 2015)

Bolivia is a country which economy has been steady increasing since the nationalization of their gas natural resources. Regarding energy, Bolivia only uses 1.2% of its hydropower potential (Plataforma Energetica, ND). Bolivia has a plan of investing 25 billion dollars for building 35 hydropower projects by 2025 that will generate 11 GW. 23 out of the 35 projects are are large dams (La Razon, 2016). Those projects will cover the local demand, and Bolivia aim to export the energy surplus to its neighbors: Argentina and Brazil.

Among the different branches of analysis that the dam developing topic has, during my research I focused on better understanding of the sediment dynamics in several Andean watersheds, how are those sediments managed on the landscape and in existing dams, and if sediment management is considered in proposed dams.

The Andes have one of the largest soil erosion rate in the world because of their high rainfall intensities and steep slopes. Therefore, sedimentation rates in reservoirs should be higher than the world average, which is 1% (George et al., 2016). Estimating those rates is one my tasks, which I will report in a subsequent article. Siltation problems are already evident in projects in the four visited countries. It is estimated, that Poechos, the largest reservoir in Peru, completed in 1997, has already lost half of its original capacity. The extreme Niño Costero event from 2017 accelerated the siltation process in this reservoir. In smaller dams visited in Ecuador, such as Ocaña, is easier to observe the sedimentation problem, and to test solutions. While in large new dams, where the problem is not so evident, some interviewed dam managers did not acknowledge the future consequence that they would face, which is storage losing.

Throughout the word, there are few dams with active sediment strategies, as for example sediment by-pass, density current venting, and sluicing among other methods to route sediment through reservoirs. These cases that have been applied in some dams in the Swiss and French Alps and in Japan, should be tested in tested in the Andes. However, in some countries, even the current environmental legislation is not suitable for sediment management in reservoirs. In Colombia, the current environmental law prohibits to dredge sediments from the reservoir and to spills them back downstream in the river, which means that the current Colombian environmental law restricts solution for allowing the river to finds its balance.

Neglecting reservoir sediment management results in water storage lost, and so it represents loss of the project benefits. If timely actions are not taken, once the sediment is compacted, removing sediments likely is unfeasibly because of its high costs. Moreover, when the reservoir is full of sediments, the dams should be removed, because it would become a potential hazard. The pressure that the saturated sediments exert against the dam is twice the pressure of the former water pressure. The Andes are in a seismic area. Therefore, when a reservoir is considerable full of sediments, dams should be removed. Dam removal costs are as high as 50% of the dam construction costs. Those costs unfortunately are not often considered in the initial cost-benefit analysis, so when this kind of cases would happen the government in office and would need to assume these expensive charges. A sustainable approach, so it is to manage sediment in dams since early stages, as well as creating a saving budget strategy per year for dam removal or major reparation when the projects meets their design life.

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