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Christoph Lehmann

Of Dams and Hurricanes: Lessons and Recommendations from El Cajon

Honduras is predominantly mountainous; its highest peaks are close to 2800 m. The country has a population of approximately 6 million and an area of 112,000 km^2. In a bid to solve its energy problems and achieve greater self-sufficiency in energy production, Honduras turned to its abundant water resources. El Cajon Reservoir, the largest civil engineering project ever undertaken in the country, was a result of this approach. At the same time, Honduras is very prone to hurricanes. The present article describes the effects of Hurricane Mitch (1998) on El Cajon dam and examines the extent to which the reservoir was able to mitigate the hurricane's impact in downstream areas. It concludes with a series of recommendations for preventive action in the event of future hurricanes.

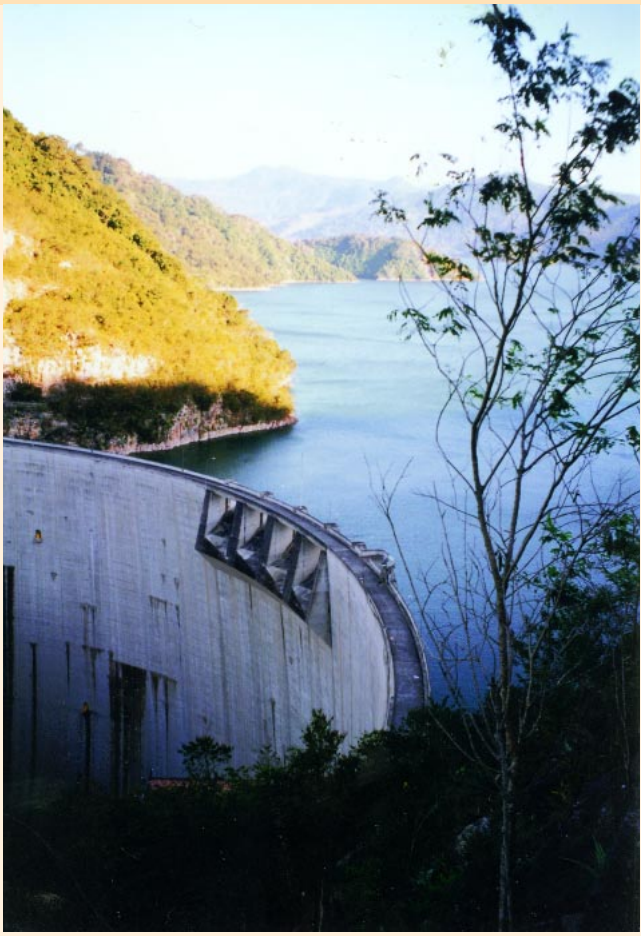


FIGURE 1 El Cajon Reservoir in central Honduras, near full capacity. (Photo by Christoph Lehmann)

El Cajon: key data in a nutshell

At a height of 226 m, El Cajon arch dam is the third highest dam in Central America and among the highest in the world (Table 1). Its total length is 382 m. Reservoir capacity is 5600 million m^3 and, at 94 km^2, the area of the reservoir surface is equal to that of Lake Yojoa, the largest natural lake in Honduras. The dam's watershed has an area of 8320 km^2. El Cajon now produces between 45 and 50% of the total energy consumed in Honduras, ie, about 650–700 kW annually (as of the late 1990s).

El Cajon: a bid to solve the country's pressing need for energy

The need for new energy resources in Honduras became obvious in the 1970s, when energy consumption grew by as much as 10% per annum, while as much as 38% of the country's energy was imported. In 1976, eg, 11% of the energy consumed was provided by electric power, 38% by petrol, and 41% by wood and charcoal. By that time, as much as 75% of the urban population had access to electric power, although this was only 20% of the total population.

As a mountainous country with moderate to high rainfall and numerous rivers, Honduras has good potential for production of hydropower. The Francisco Morazán Reservoir, better known as "El Cajon" (Figure 1), was therefore planned to cover the country's future electricity needs. El Cajon was expected to provide the country with more than half of its energy supply. Construction of the reservoir was carried out between 1980 and 1985 by an international consortium composed largely of European companies. The site selected for the dam was the Comayagua River watershed in the central part of Honduras near Lake Yojoa, a large natural lake remarkable for its fish resources and the beautiful mountain landscapes that surround it. This site is half-way between the capital city of Tegucigalpa and the city of San Pedro Sula, the economic center of the country (Figure 2). The area benefits from ample rainfall, with average precipitation totaling up to 1300 mm annually, which is moderate compared with other mountain regions in Honduras, where annual totals can range between 2000 and 3000 mm.

The challenge of estimating discharge and sedimentation rates

At the planning stage, the maximum input discharge into the reservoir was estimated at 22,850 m^3/s, and total water volume at 3200 million m^3. This maximum input discharge was five times higher than the modeled input discharge of Hurricane Fifi, which would have reached a peak discharge of 4500 m^3/s (Table 2), according to calculations. And it was 12 times higher

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than discharge from any other flood observed in the area up to the time of the dam's construction. Fifi, which struck Honduras in September 1974, was the largest hurricane in the country in preceding decades. As relatively good records existed for the hurricane's precipitation and discharge, it was taken as a reference for calculating the maximum discharge and discharge volumes of El Cajon. Sediment input was estimated to be about 4.88 million m^3/y, or between 250 and 372 million m^3 in the first 50 years, depending on the model applied. This corresponds to less than 7% of the total reservoir volume of 5600 million m^3. This sedimentation rate results in a reservoir lifetime of more than 1000 years. Sedimentation was thus assumed to be no threat to the viability of the dam. However, sediment input into the reservoir has never been measured since the dam has been in operation.

El Cajon during Hurricane Mitch

The Central American countries are very prone to hurricanes, which generally trigger other hazards such as landslides and extensive floods. Hurricane Mitch gained the world's attention in October 1998 due to the disastrous course it took over several countries in the region. Its effects were so devastating that it is regarded as one of the most destructive natural hazards ever experienced in Central America. In Honduras alone, it caused 5600 deaths and left approximately 285,000 people homeless. Total property damage was estimated at US$ 5 billion. Floods resulting from excessive rainfall caused the main damage in Honduras, but landslides and disastrous winds also played an important role.

Fortunately, total rainfall during Mitch was less extensive in the central part of Honduras where the El Cajon watershed (Figure 3) is located. Total precipitation was between 400 and 600 mm, compared with approximately 1000 mm in the north and as much as 1600 mm in the south. Nevertheless, these 400–600 mm constituted an extraordinary event for the El Cajon area, representing about half its total annual rainfall. The year 1998 had been a dry year before Mitch struck in October. This was the reason why the water level in the reservoir was only at about 262 m when the hurricane passed over the area. This is 26 m below the normal fill height of about 288 m. This was a lucky coincidence since the heavy rainfall brought by Mitch added enormous masses of water to the reservoir, with peak discharge values reaching more than 7000 m^3/s (Table 2). The total volume of water entering the lake was roughly 2600 million m^3 (equivalent to a cubic measure of $1 \times 1 \times 2.6$ km!). The water level in the reservoir rose 26 m to the dam's normal fill height in a period of several days.

According to feasibility studies for El Cajon prior to construction, a hurricane the size of Mitch was assumed to have a return period of 60 to 600 years in relation to the rainfall regime prevailing in the dam's watershed. Given this assumption, it is interesting to compare the planning figures used for dam construction with the values for Mitch (Table 2). Obviously, maximum input discharge by Mitch was higher than the value calculated for Fifi but still about three times smaller than maximum tolerable input discharge. The same holds

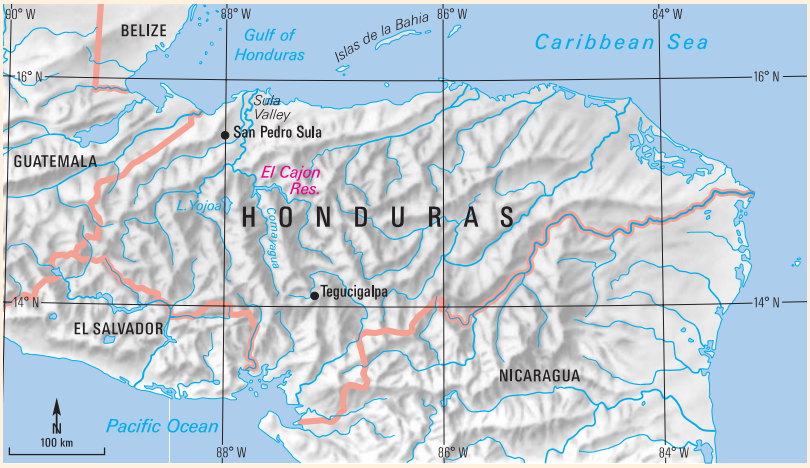


FIGURE 2 Map of Honduras, showing the location of El Cajon Reservoir and the city of San Pedro Sula at the edge of an extensive lowland area. (Map by Andreas Brodbeck)

TABLE 1 The highest dams in the Americas and the world's highest dams. (Sources: The Learning Network Inc., Kasetsart University, Bangkok; http://www.infoplease.com/ipa/A0001334.html; http://is1.eng.ku.ac.th/~irre/E10TALL.HTM.)

	Country	Dam height (m)	Year completed
Highest dams in Americas			
Manuel Torres	Mexico	261	1981
Alvaro Obregon	Mexico	260	1926
Mica	Canada	243	1972
Alberto Lleras	Colombia	237	1975
El Cajon	Honduras	234	1984
World's highest dams			
Rogun	Tajikistan	335	2003
Nurek	Tajikistan	300	1980
Grand Dixence	Switzerland	285	1962

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FIGURE 3 View of the El Cajon watershed, which is dominated by pine forests. (Photo by Markus Zimmermann)

true for the input volume, which was three times higher than the value calculated with the dates for Fifi but still well below the maximum tolerable value.

Taking into consideration that modeling extreme natural events is a difficult undertaking, especially in the absence of reliable long-term data, the planning figures used for dam construction appear to be realistic while still providing a safety margin, even in the case of extreme events such as Hurricane Mitch. Interestingly, however, there are indications that sediment rates might be considerably higher than anticipated, especially during disastrous events such as Mitch. There are current plans to start measuring sediment input from the most important rivers that drain into the reservoir.

Another important question concerns the impact of the dam on flood prevention. When Hurricane Mitch struck, the water level in the reservoir was at 262 m, corresponding to a surface area of 73 km^2 in the lake. At the fill height of 288 m, the surface area is 97 km^2. The rise in the water level from 262 to 288 m resulted in a total increase in volume of 600 million m^3. Given the total inflow volume of 2600 million m^3, as much as 2000 million m^3 of water must have flowed out of the lake during the hurricane (Table 2). This figure can be closely correlated with the volume of water reported by the energy authorities to have left the dam. It can thus be stated with some degree of certainty that about 25% of the total discharge volume during the hurricane was retained by the reservoir while over 75% flowed down the Comayagua River into the densely populated Sula Valley (Figure 4). More important than this seemingly limited effect of El Cajon was the great reduction of peak discharge effected by the lake. While peak discharges into the reservoir reached over 7000 m^3/s, maximum discharge from the lake never exceeded 1400 m^3/s. This corresponds to a reduction of 80%.

FIGURE 4 View of the Sula Valley 1½ years after Hurricane Mitch, showing the city of San Pedro Sula in the background. The densely settled valley was directly in the path of the discharge that flowed down the Comayagua River in the wake of the hurricane. (Photo by Christoph Lehmann)



Future mitigation of the downstream effects of hurricanes

While detailed official calculations have not yet been made, it can be stated that El Cajon had two main impacts on the floods caused by Hurricane Mitch: a delay of discharge and a very substantial reduction of peak discharge. If the 600 million m^3 of water retained by the reservoir had gone downstream in addition to what flowed down the valley and if peak discharges had not been greatly reduced, the flood would have inflicted much more serious damage than what was observed, especially in the densely populated Sula Valley. However, the mitigating role of El Cajon was enhanced by the exceptionally low dam filling level in October 1998. With normal water levels, maximum discharge and discharge volumes would have been greater. The possibility that the central part of Honduras, and hence the El Cajon watershed, will be struck again by strong hurricanes in the future cannot be ruled out, especially in light of climate change, which could increase hurricane frequency in this part of the country. Considering this possibility, what are the options for reducing the risk of downstream destruction? The following is a short overview of these options and the role the dam could play in helping prevent disasters in the future.

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TABLE 2 El Cajon dam: Discharge and discharge volumes during Hurricane Mitch compared with values for Fifi and maximum values projected by models used during dam construction. (Source: Motor–Columbus Consulting Engineers Inc and calculations by author.)

Event/database (modeled values in italics)	Maximum input discharge into reservoir (m^3/s)	Maximum output discharge from reservoir (m^3/s)	Total input volume into reservoir (Mm^3)	Total output volume from reservoir (Mm^3)
Hurricane Mitch (1998)	7000	1400	2600	2000
Hurricane Fifi (1974)	*4500*	Not calculated	*750*	Not calculated
Maximum tolerable input	*22,850*	Not calculated	*3200*	Not calculated

Management of dam water level

Attractive as this option appears to be, it has clear limitations in practice. The warning time for a hurricane is not longer than a few days and its probable path is known only very shortly before it appears; a significant reduction of the water level in the dam is not possible on such short notice. Nor is it possible to keep the water level low during the rainy season in anticipation of a hurricane that might appear toward the end of the rainy season (eg, in October) since the remaining rains would most likely not fill the dam. This would affect the electricity production on which the country heavily depends during the dry season. Moreover, a safety margin must be provided in the event of emergencies such as prolonged dry seasons or drought.

Flood forecasting based on hydrometeorological data

Even with a dense recording network, discharge forecasts cannot be made for more than a few days in advance, even if real-time data were available. While such forecasts can help in making short-time calculations of discharge into the reservoir, the warning time is still too short for managing, ie, reducing, the water level in the reservoir and preventing a spate. However, an early warning system could provide the data needed for long-term calculations of the precipitation/discharge behavior of the El Cajon watershed, which would allow general improvement of reservoir management.

Flood zones in downstream areas

As measures of reservoir management have their limitations, interventions such as planning an effective flood control system in the Sula Valley in the downstream areas come into play. Initiatives are currently underway to this end. Flood zones could help distribute and store floodwaters, but it is difficult to set aside such areas because settlement and population density are very high in the valley and flood zones would cover extensive areas. In order to retain a volume of 600 million m^3 of water, which was the volume retained by El Cajon during Hurricane Mitch, an area of approximately 300 km^2 (assuming an average fill height of 2 m) would be necessary. This corresponds to one sixth of the total area of the Sula Valley. The limitations of a flood control approach are thus obvious.

Improving the flow capacity of the main rivers in downstream areas

Local construction of large channels is possible under present conditions in the Sula Valley. However, this approach alone cannot solve the problem of flood risk sustainably, as examples from all over the world have proven, for the simple reason that flood peaks are simply and more rapidly transferred to regions further downstream.

Early warning systems and contingency plans

In light of the limitations of purely technical measures and especially with regard to the fact that El Cajon is not the only river that drains into the Sula Valley, an early warning system for downstream areas seems to be a good idea at first look. However, such a system is not without its problems. It should be part of a comprehensive contingency plan that includes all municipalities in the Sula Valley. Alert levels need to be defined, and it must be clear in advance who has to be evacuated at what level and where people will be moved to and by what means. Emergency committees must be set up and trained, and people have to be informed about emergency scenarios and what they will have to do in case of an extreme event. At present, the Sula Valley municipalities are still far from this level of preparation. Efforts will have to be made in this direction in order to prevent a major disaster in the future.

FURTHER READING

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Christoph Lehmann is a geomorphologist. He earned a PhD in geography at the University of Berne, Switzerland. A specialist in natural hazard prevention, he works as a freelance consultant. He is currently on assignment in Honduras for projects in disaster prevention jointly run by UNDP and the Swiss Agency for Development and Cooperation (SDC).

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