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Sandro Velić
E-mail: sandrovelic@gmail.com
Mate Barić
E-mail: mbaric@unizd.hr
Ivan Toman
E-mail: itoman@unizd.hr
University of Zadar, Maritime Department, Mihovila Pavlinovića 1, 23000 Zadar, Croatia
Leonardo Šango
E-mail: leonardo.sango@skole.hr
Maritime high school Zadar, Ante Kuzmanića 1, 23000 Zadar, Croatia

Impact of Gatun Lake Water Level on Safety of Navigation in the Panama Canal

Abstract

Since its last expansion, the Panama Canal is able to handle even bigger ships that sail through that important bridge between two oceans. Such expansion in ship size brings higher demands regarding the safety of navigation, especially in restricted fairways like the Culebra cut. However, the water level in the Panama Canal has a large impact on the safety of navigation. If the water level is too low, the safety of navigation can be endangered throughout the entire Canal. This paper analyses the impact of droughts on the navigation through the Panama Canal and its influence on canal operations. Since the lakes are mostly supplied through rainfall, future droughts could largely impact the Panama Canal traffic and prevent increase in traffic despite bigger locks.

Keywords: Panama Canal, safety of navigation, droughts

1. Introduction

Since its opening in 1914, the Panama Canal has been the major connection for shipping between the Pacific and the Atlantic Ocean. Shortening the passage of ships by more than 6500 miles between the aforementioned oceans, it represents the shortest shipping route for trade between the US East Coast and Asia till today. However,

regarding the ship size, the Canal was limited with the lock size which connected the Gatun Lake with the oceans. The size of the original locks permitted ships up to 294 meters long, 32 meters wide, with the maximum draft of 12.6 meters [12]. In time, restricted ship size became a limiting factor since ship size was increasing [15]. Due to such steady increment in vessel size, the Canal had to expand the lock size. In 2016 new locks became operational allowing bigger vessels to pass the Canal. New locks can accommodate ships up to 370 meters long and 49 meters wide, with a draft of up to 17 meters [10]. With the increase in lock size, a new name for maximum allowed vessel size was introduced, known as Neo-Panamax. Since 2016 the statistics show that the number of container ships, as well as LNG and LPG tankers passing through the Canal has significantly increased. Also, all other ship types show increment in traffic [2]. However, that increment has lately been limited by weather conditions in the Canal area, particularly by droughts. Since its opening in 2016, the traffic in the Canal is often restricted by maximum ship draft. The main reason for that is the lack of rain and limited water level in Gatun Lake.

2. Panama rainfall and climate

Easterly trade winds dominate this region, transporting moisture from the Caribbean Sea, allowing for orographic rainfall as the moist air is forced upward by Panama's mountainous terrain.

However, Panama has two main seasons regarding rainfall, the drought season from December to April and the rain season from May to November. Precipitation seasonality in this region is driven by seasonal changes in the position of the Intertropical Convergence Zone (ITCZ). While during wet season its proximity allows for a widespread convective activity, often in the form of intense afternoon thunderstorms, during dry season ITCZ shifts southward, leaving this area within predominantly stable trade wind weather patterns [8]. As shown in Figure 1, the average rainfall from 1991 to 2020 followed the pattern of the aforementioned seasons [17].

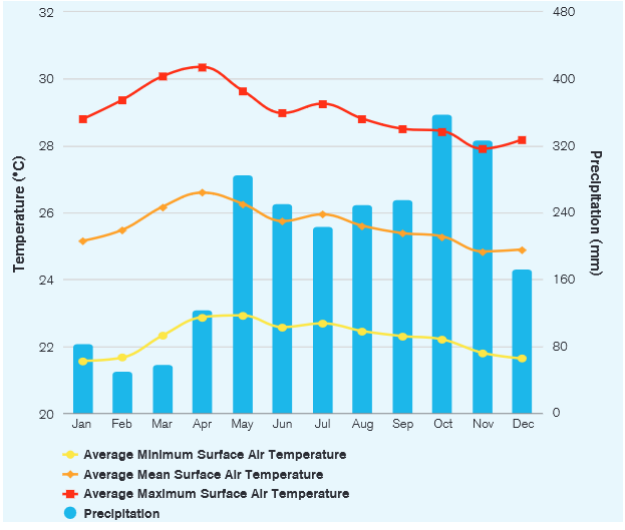

Figure 1. Average temperatures (lines) and precipitation (bars) from 1991 to 2020 in Panama [17].

Long-term annual precipitation average in Panama is 2436.21 mm. However, during the period from 2020 to 2024, the amount of precipitation significantly decreased as shown in Figure 2. The yearly sums for that period are below 2000 mm, and only 2022 had the yearly sum above 2000 mm.

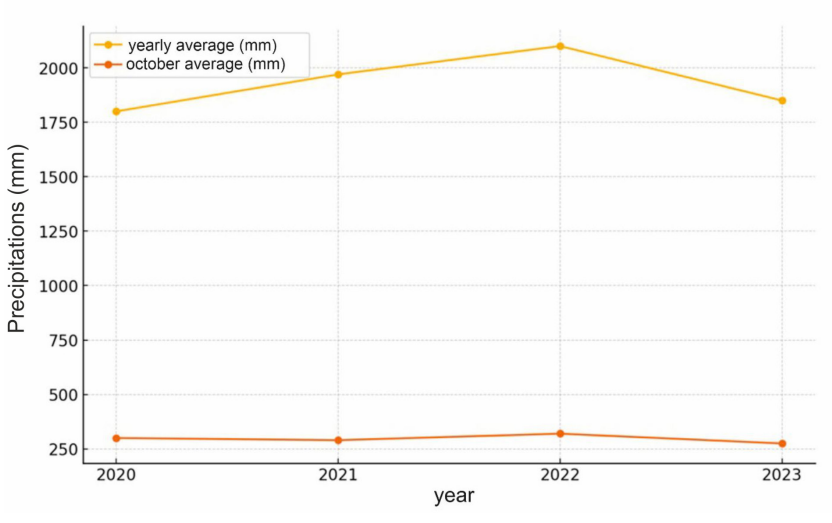

Figure 2. Yearly and October rainfall sums in Panama from 2020 to 2023 [16].

October is the wettest month in the long term with average monthly amount of around 350 mm (Figure 1). During the period from 2020 to 2023, the October rainfall sums were also lower than normal (Figure 2), which implies possible problems with water supply into the Canal.

Gatun Lake represents the central water reservoir for the Canal and the population of Panama. The lake is mostly supplied by water from the river Charges. The river brings water from the central mountain range. However, changes in precipitation affect the river and Gatun Lake. In the last four years (2019 to 2023), the water level in Gatun Lake has fluctuated. During 2019 there was a great drought which resulted in the reduction of water level in the lake by 0.91 meters below average. During 2020 and 2021 the water level was still low, fluctuating between 0.6 to 0.9 meters below normal. Figure 3 represents the anomalies in precipitation and Gatun Lake water level. Precipitation is shown in percentage below average, and the lake water level in metres below average.

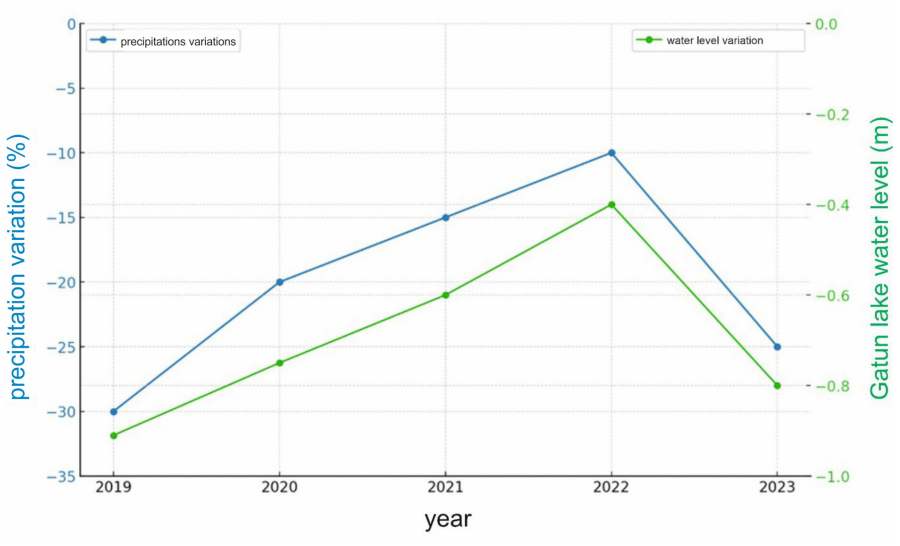

Figure 3. Precipitation and Gatun Lake water level anomalies from 2019 to 2023 [3].

Apart from the already mentioned seasonal changes in precipitation patterns, caused by shifting ITCZ closer or further away from the region, various teleconnections influence weather in the Panama Canal. Most notably, El Niño-Southern Oscillation (ENSO) is a strong driver of total precipitation amounts. Particularly, during the warm (El Niño) ENSO phase, Panama experiences drier than normal conditions, as El Niño typically shifts ITCZ further south than normal. On the other hand, cold (La Niña) ENSO phase keeps ITCZ closer to the region, bringing wetter than average conditions due to enhanced convection and moisture transport in the region [4].

Apart from ENSO, other large-scale phenomena affect weather patterns in Panama. Atlantic Multidecadal Oscillation (AMO) during the warm phase increases the Atlantic Ocean surface temperature, resulting in elevated heat and moisture fluxes into tropical maritime airmass. Consequently, easterly trade winds bring more moisture into the region which increases precipitation amounts. However, during the cold AMO phase, situation reverses, leaving Panama with less moisture influx from the Atlantic than normal and thus less rain [6].

There are other teleconnections that might influence weather patterns in Panama, for example Madden-Julian Oscillation (MJO), as well as Pacific Decadal Oscillation (PDO). Their effects are usually weaker compared to ENSO [1].

Apart from the effects of various planetary-scale oscillations, with periods between years and decades, there is the effect of global warming, particularly on water temperatures. As warmer water evaporates more quickly, larger amounts of precipitation are required to keep water level in balance over long periods (like decades). However, there are currently limited research studies on this topic for the Panama Canal.

Future climate projections mostly suggest that the Panama region will experience an increase in the total yearly precipitation amounts, mostly as a result of the warmer Caribbean Sea in the following decades [5]. Such increase should be sufficient to offset additional evaporation caused by the increase in Gatun Lake water temperature, so the Panama Canal should not run out of water supply. However, when taking into consideration the reconstructions made to accommodate larger vessels, this water supply might not be enough in the future, as the demand for water will significantly increase.

3. Impact on traffic

In the past five years, the Panama Canal Authority has repeatedly imposed draft restrictions on vessels during transit. According to the Panama Canal advisory to shipping in 2019 there were 12 updates to maximum authorised draft for Neo-Panamax locks (Advisory to shipping number: A-01-2019, A-03-2019, A-05-2019, A-06-2019, A-08-2019, A-10-2019, A-13-2019, A-15-2019, A-19-2019, A-21-2019, A-23-2019, A-24-2019, A-28-2019, A-35-2019). The first advisory in February 2019 (A-01-2019) had the largest limited draft for Neo-Panamax locks of 14.95 meters. The lowest limited draft of 13.11 meters for Neo-Panamax locks was imposed during the end of May 2019 (A-13-2019). The lowest required draft is 13.89 meters under the maximum permissible, which is a limiting factor for certain ship types and sizes. During 2020, there were 9 updates regarding the maximum authorised draft for Neo-Panamax locks (Advisory to shipping number: A-07-2020, A-09-2020, A-15-2020, A-18-2020, A-21-2020, A-25-2020, A-27-2020, A-32-2020, A-35-2020). Advisory A-09-2020 from April 2020 limited the ship draft to 13.53 meters. After that the limited draft was increased to the maximum of 15.25 meters in September 2020 (A-35-2020). In 2021 there were 6 updates to maximum authorised draft for Neo-Panamax locks (Advisory to shipping

number: A-10-2021, A-17-2021, A-18-2021, A-20-2021, A-23-2021, A-27-2021). In 2021 the minimum draft was 14.63 m (A-18-2021) during March. In comparison to 2020, it is 0.74 meters increment in permitted ship draft. During 2022 there were 8 updates to maximum authorised draft for Neo-Panamax locks (Advisory to shipping number: A-02-2022, A-05-2022, A-08-2022, A-10-2022, A-13-2022, A-15-2022, A-16-2022, A-18-2022). In April 2022 the limited draft was 14.94 meters, which is an increment of 0.32 meters in comparison with 2021. During 2023 there were 12 updates to maximum authorised draft for Neo-Panamax locks (Advisory to shipping number: A-02-2023, A-04-2023, A-08-2023, A-09-2023, A-14-2023, A-16-2023, A-17-2023, A-18-2023, A-20-2023, A-22-2023, A-23-2023, A-30-2023). The lowest limited draft was 13.26 meters in June 2023. That is a drop of 1.68 meters in comparison to 2022. Figure 4 shows the lowest limited draft and the number of draft limitations.

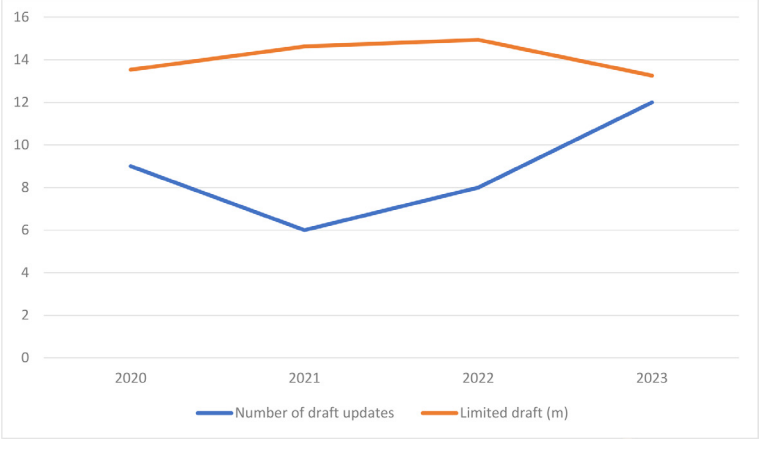

Figure 4. Number of draft updates and minimum limited draft for the Panama Canal from 2020 to 2023.

The comparison between precipitation anomalies (Figure 3) and draft limitations (Figure 4) shows that the two correlate. It is also evident that rainy seasons have not delivered the expected precipitation levels, raising concerns about the anticipated traffic volume in the Canal. The water level of Gatun Lake serves as the key indicator of overall water availability.

Figure 5 presents the distribution of Gatun Lake water levels throughout the year from 2019 to 2023. The lowest levels were recorded in 2019 and 2023. Notably, the water level during the dry season was comparable to that of the rainy season, highlighting a concerning trend. For instance, in December 2022, the lake water level was 88 feet, whereas in December 2023 it dropped to 81 feet.

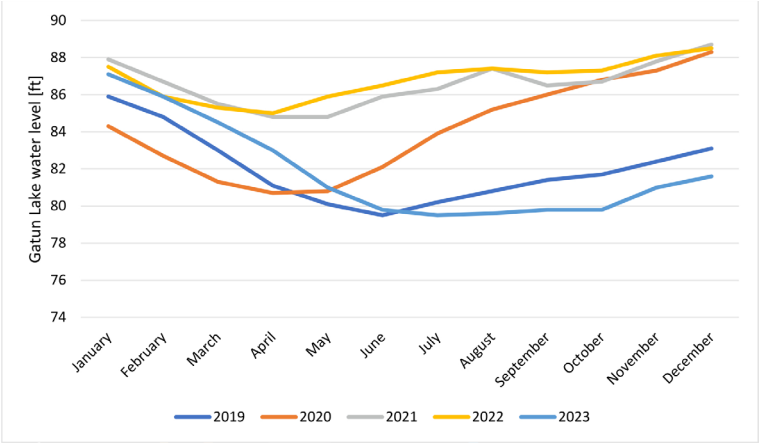

Figure 5. Gatun Lake monthly water levels from 2019 to 2023 [13].

The low water level in 2023 caused disturbance in the Canal traffic. Figure 6 shows the total vessel tonnage through the Canal from 2021 to 2023. It shows a prominent decrease which could be due to the fact that 2023 was the driest year in Panama history [9].

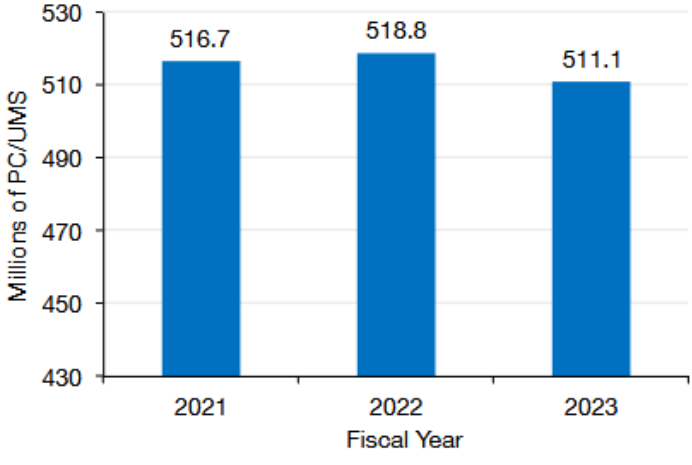

Figure 6. The total number of vessel tonnage annually from 2021 to 2023 [9].

Since the opening of Neo-Panamax locks, during 2023 two ship passages broke the size record. However, those records were achieved by partial discharging of cargo. The first ship was Ever Max, which is a 366 meters long container ship with 15372

TEU capacity. At the time of transit, in August 2023, the safety of navigation could be achieved only by reducing the amount of cargo on board. Upon arrival in the port of Balboa, the cargo of 1400 TEU was unloaded on a train and transported to the port of Colon. That way, the draft of the ship was reduced from 15.24 meters to at that time allowed 13.41 meters. This operation could not be done with any other type of ship, and it incurred additional expenses for the shipowner. A similar situation happened with the bigger ship MSC Marie. MSC Marie transited the Panama Canal on 30 August 2024 and set a new record on ship size in the Panama Canal. MSC Marie is a container ship, 366 meters long with a maximum capacity of 17640 TEUs. However, on arrival the ship draft was larger than the maximum allowed of 14.63 meters. So, in this case, like before, the draft was reduced by unloading containers on one side of the Panama Canal and transporting them to other side of the Panama Canal.

4. Discussion

The analysis of the presented data clearly shows that the ship transit in Panama Canal may vary during the year. The variations are increasingly affected by precipitation, specifically, lack of it. From 2016 the Panama Canal expanded its locks to Neo-Panamax ship allowing bigger vessels to transit the Canal. However, the expansion is hindered and partially offset by insufficient precipitation and low water levels.

A comparison of water levels in Gatun Lake, the largest reservoir in the country and the primary water source for the Panama Canal, reveals that in recent years, levels have been significantly below average. This trend is particularly evident in 2023 and 2024 (Figure 7).

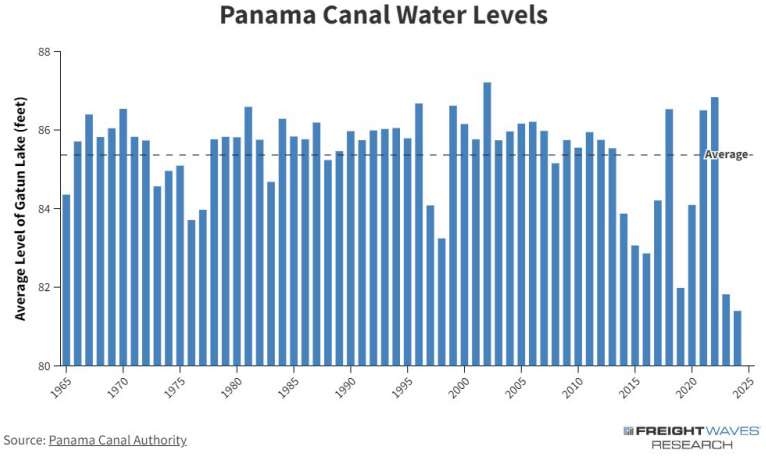

Figure 7. Gatun Lake water level from 1965 to 2024 [7].

According to the Panama Canal Authority, the rate of successful transit in 2075 could be significantly reduced for larger ships. Table 1 compares the expected successful transits in 2025 and 2075. According to predictions for 2025, the success rate for transits of ships with the maximum allowed draft is expected to be 52.5%, and by 2075, this rate will decline even further. A significant issue arises when transit success rate for ships with drafts exceeding 14 meters drops from the expected 90.4% to 62.2% by 2075. This decline suggests that the benefits of the Neo-Panamax lock upgrade, without changes to canal dimensions or water management, will be effectively nullified. Addressing this challenge will require ongoing upgrades and adaptive measures.

Table 1. Comparison of successful transit rate in 2025 and 2075 [11].

	Current conditions and size (2025)	Current conditions and size (2075)	Difference
Successful transit rate			
Transits (total)	98.7%	86.1%	-12.6%
Maximum allowed draft	Maximum draft limitations frequency		
50 ft (15.24m)	52.5%	23.4%	-29.1%
48 ft (14.63m)	78.9%	43.8%	-35.1%
46 ft (14m)	90.4%	62.2%	-28.2%
44 ft (13.41m)	96.0%	92.1%*	-3.9%
39.5 ft (12.03m)	96.2%	93.6%*	-3.8%

The impact of drought is already evident, and future predictions may be even more severe than those presented in Table 1. In 2023, the number of available daily transit slots ranged from 32 to 34. By 2024, this number declined further, averaging between 30 and 32. This reduction suggests that the effects of drought remained comparable to the previous year, with increasing concerns shifting toward water management (Figure 8).

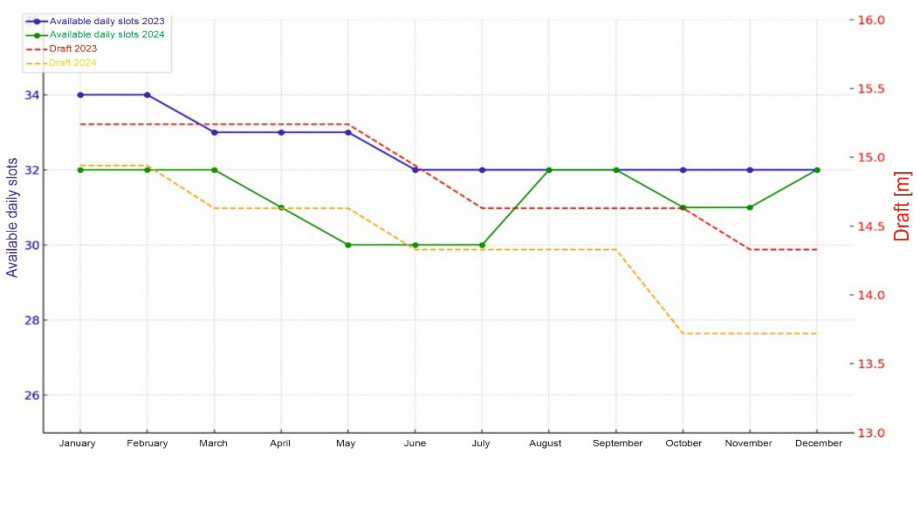

Figure 8. Available day transit slots and draft in 2023 and 2024 [14].

Similar reduction happened to the allowed maximum ship draft in the Canal. The decline is especially visible from October to December. In that period, the amount of precipitation did not reach climatological average. Such conditions forced the authority to reduce the available slots and maximum draft. This situation repeated two years in a row and in the future, a lot of water supply upgrades should be made to maintain Canal water availability and vessel throughput.

5. Conclusion

The Panama Canal, a vital link between the Pacific and the Atlantic Ocean, faces increasing challenges due to water level fluctuation, driven by shifting precipitation patterns and climate influences. While the expansion to Neo-Panamax locks has allowed for larger vessels, the effectiveness of these upgrades is hindered by recurring droughts and declining water levels in Gatun Lake. This study highlights that water scarcity impacts navigation safety, vessel drafts, and overall transit capacity. As climate models predict further variability in precipitation, the Panama Canal Authority must prioritize sustainable water management strategies and infrastructure upgrades to mitigate these challenges. Without such measures, the Canal capacity to accommodate larger vessels and maintain its pivotal role in the global trade may be significantly compromised in the decades ahead.

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