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Learning Lessons from Derna Dam Failures

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A B S T R A C T

The dams in Libya have been built primarily for flood control, as seen with the Wadi Darna, Wadi Mejenin, and Wadi Qattarah Dams, as well as for supplying water to agricultural regions, including the Wadi Mejenin, Wadi Kaam, and Wadi Qattarah Dams. However, the effectiveness of these structures in managing floods and providing agricultural water has been inadequate. A recent example of this is the devastating dam failures at Wadi Derna, when the dams did not protect the city but instead the flood was made worse. Nevertheless, the destructive "Storm Daniel" event that struck northeastern Libya recently exceeded even the rainfall's dam design capability. Additionally, the dams' long-term flows and rainfall should be re-evaluated, and the size of the spillway and gates should be confirmed to determine whether the structures could sustain more severe floods like Daniel. The failure of the Derna and Abu Mansour dams offers significant insights for enhancing dam safety in Libya, particularly concerning the nine large dams. It is essential to assess all Libyan dams regarding their design, safety measures, and structural integrity to avert similar catastrophic incidents both in Libya and worldwide. It is essential to establish early warning systems to mitigate the impact of natural disasters. Creating flood hazard and risk maps in areas susceptible to flooding, particularly in seasonal wadis, which will serve as a foundation for developing future flood risk management strategies.

الدروس المستفادة من إنهيار سدي درنة

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الكلمات المفتاحية:
انهيار السدود
العاصفة دانيال
السدود الليبية
تقييم السد
سد درنة
مجرى تصريف المياه
.

الملخص

تم بناء السدود في ليبيا بشكل أساسي للسيطرة على الفيضانات، كما هو الحال في سدود وادي درنة ووادي مجنين ووادي قطارة ، وكذلك لتزويد المناطق الزراعية بالمياه كما هو الحال سدود وادي مجنن ووادي كعام ووادي قطارة فعالية هذه السدود في إدارة الفيضانات وتوفير المياه الزراعية لم تكن ناجحة. ومن الأمثلة الحديثة على ذلك الانهيار المدمر للسدود في وادي درنة، حيث ان السدود لم تحمي المدينة ولكن بدلا من ذلك زادة الفيضان سوءا. ومع ذلك، فإن حدث "العاصفة دانيال" المدمر الذي ضرب شمال شرق ليبيا مؤخرا كانت فيه كمية هطول الأمطار قد تجاوز حتى قدرة تصميم السد. بالإضافة إلى ذلك ، يجب إعادة تقييم تدفقات السدود على المدى الطويل وهطول الأمطار ، ويجب تأكيد حجم مجرى تصريف المياه والبوابات لتحديد ما إذا كانت السدود يمكن أن تتحمل فيضانات أكثر شدة مثل دانيال. يقدم انهيار سدي درنة وأبو منصور رؤى مهمة لتعزيز سلامة السدود في ليبيا ، لا سيما فيما يتعلق بالسدود التسعة الكبيرة. من الضروري تقييم جميع السدود الليبية من حيث تصميمها وتدابير السلامة والسلامة الهيكلية لتجنب وقوع حوادث كارثية مماثلة في كل من ليبيا والعالم. ومن الضروري إنشاء نظم للإنذار المبكر للتخفيف من آثار الكوارث الطبيعية. إنشاء خرائط لمخاطر الفيضانات والمخاطر في المناطق المعرضة للفيضانات ، لا سيما في الوديان الموسمية ، والتي ستكون بمثابة أساس لتطوير استراتيجيات إدارة مخاطر الفيضانات في المستقبل.

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1. Introduction

The dams are a manmade structure or naturally occurring barrier across a river, which controls the flowing water. The purposes of building the dams are irrigation water supply for agriculture, control of floods, generating energy (hydropower), and others. [1]. According to The General Water Authority [2], eighteen dams have been constructed in eastern, western and central Libya in the past four decades. We detected thirteen smaller dams by remote sensing beside the eighteen dams Fig (1). Dams were established in Libya in order to control floods and supply agricultural areas with water. The design capacity of the eighteen dams constructed in Libya at the ephemeral streams was determined to be nearly 390 million cubic meters.

By comparison, the annual storage capacity of these dams does not exceed 62 million cubic meters of water [2], and [3] The difference between the annual water retention and the design capacity could be caused by inadequate annual rainfall or by design flaws that resulted in the reservation of tiny amounts of the desired water, particularly for the big dams (Wadi Qattarah and Wadi Kaam). According to International Commission On Large Dams [4], and [5] definition of large dam “A dam with a height of 15 meters or greater from lowest foundation to crest or a dam between 5 meters and 15 meters impounding more than 3 million cubic meters.“ Libya has only nine large dams, Figs (1, 2 and table 1) dams 1 through 9, which are Qattarah, Wadi Kaam, Al Majnin-1 and 2, Wadi Ganh, Abu Mansour (failed), Wadi Zarat, Wadi Lebda, and Al washka dams Table (1). However, shows the remaining 22 dams consist of eight relatively large dams such as Al Zahawiya, Wadi Al Zaid, Wadi Gaaref, Wadi Zazah, Wadi Tabereat, wadi Al Dikr, Qattarah secondary and Derna (failed). The other 14 dams are small in both their height and reservoir capacity.

This paper aims to identify a set of safety goals for the remaining dams in Libya by drawing several critical lessons from the catastrophic breakdown of Wadi Derna dams.

2.0 Wadi Derna Dams

Derna City is located on an alluvial fan in the narrow coastal plain at the mouth of Wadi Derna in the front of a bold fault scarp. Wadi Derna originates from Al Jabal Al Alakdar with elevation about 770m a.s.l and flows west-east and eventually changes the flow direction from

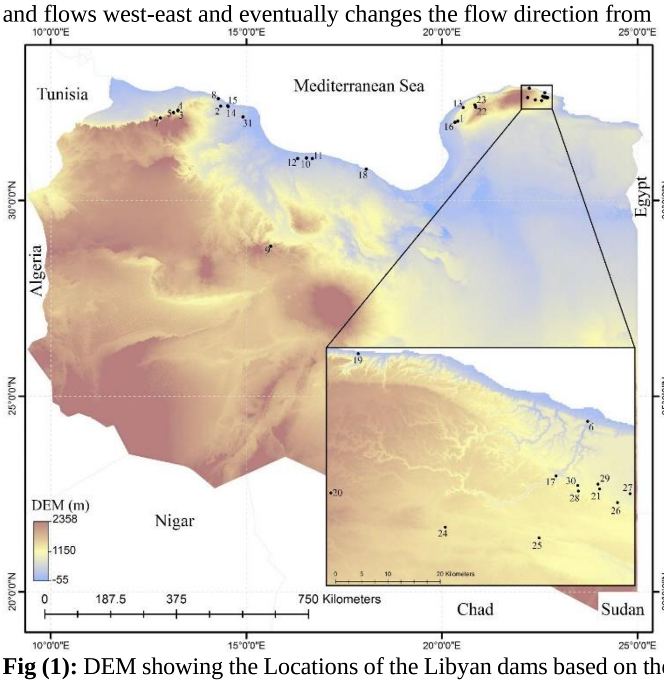

Fig (1): DEM showing the Locations of the Libyan dams based on the reservoir capacity GWA (2012) and updated through remote sensing data. Dams 1 through 9 are large dams accoriding to (ICOLD) defination of lrage dams. . 1-Qattarah, 2-Wadi Kaam, 3-Al-Majnin-1, 4-Al-Majnin-2, 5-Wadi Ganh, 6-Bu Mansour, 7-Wadi zarat, 8-Wadi Lebda, 9-Al-Washka, 10-Al-Zahawiya, 11-Wadi Al Zaid, 12-Wadi Gaaref, 13-Wadi Zazah, 14-Wadi Tabreat, 15-Wadi Al Dikr, 16-Qattarah Secondary, 17-Darna, 18-Bin Jawad, 19-Wadi Markus, 20-Al Mullaq Dam-1, 21-East Derna-1, 22-Angood Dam, 23-El-Gowd Dam, 24-Um Whathab Dam, 25-Al Mullaq Dam-2, 26-East Derna-2, 27-NW Martuba, 28-W. Derna branch-1, 29-Nasho Dam, 30-Wadi Derna branch-2, 31-Wadi Saso Dam.

south to north and bisects Derna city in two parts and ending up to the Mediterranean coastline. Since the city of Darna has experienced frequent floods in the past, therefore the government decided to build two dams to protect the city from flash floods. The basic function of Wadi Derna dams to control flooding and protect the city of Derna from a catchment area equal to (457 km^2) along with Bu Mansur dam and controlling flood from the catchment (97 km^2) along with Wadi Derna dam. Beside other functions such as recharge the aquifers and provide water for the Fataya Agricultural Project. Both dams were constructed between 1973 to 1977 along Wadi Derna by Hidroprojekat, Yugoslavian company.

The Bu Mansour dam was a 73 m high rockfill embankment dam with a clay core located about 11 km upstream of the Derna dam. The reservoir was designed to store 22.3 MCM (million cubic meters) and the dam to carry a flood discharge of 170 m^3/s over a shaft spillway

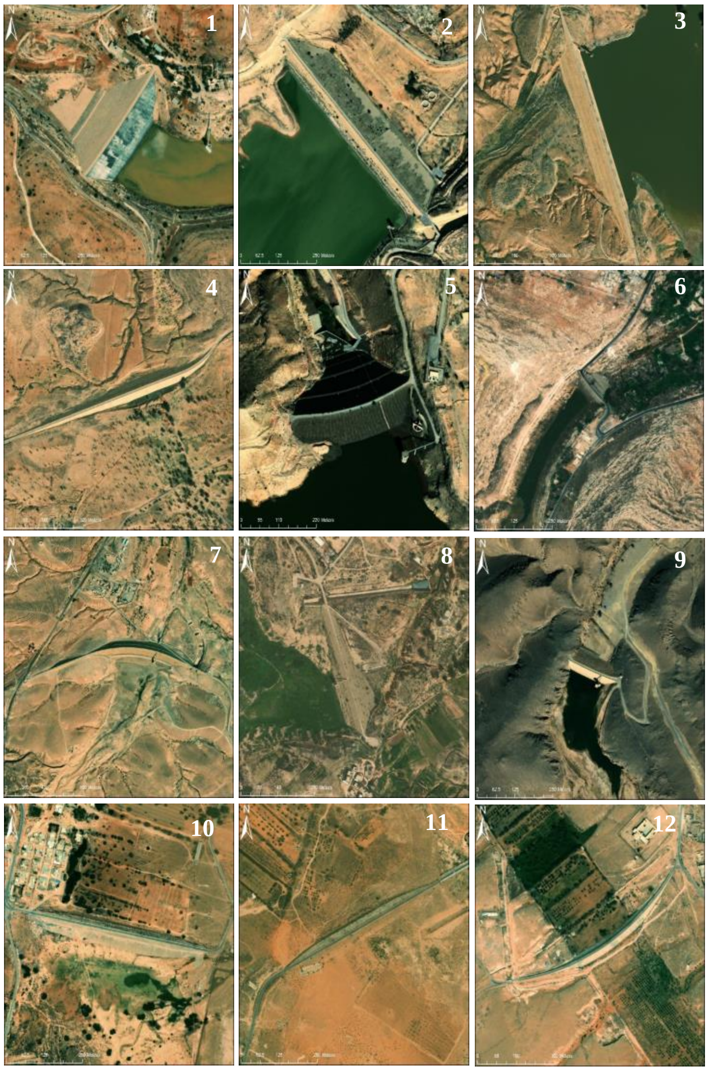

Fig (2) Satellites images for the Libyan dams. For the dam name and location, refer to Fig (1) and Table (1). Dams 1 to 9 are large dams according to (ICOLD).

(a morning glory) set at an elevation of 224m a.s.l. The Derna dam (Belad dam) was a 45m high, rockfill embankment dam with a clay core located about 1 km upstream of the city of Derna. The reservoir was designed to store 1.15 MCM and the dam to carry a flood discharge of 350 m3/s over shaft spillway (a morning glory) set at an elevation of 41m a.s.l table (2) [6], [7], [8] [9], and [10 -17].

3.0 Learning Lessons from Derna Dam Failures:

Storm Daniel, an unprecedented storm that fell heavily on northeastern part of Libya on September 10, and 11, 2023, caused Derna dams to fail, resulting in a catastrophic flood event that had never been seen before. According to the witness, the first flood wave hit the city around 23:00 on September 10. This followed by a second flood around 02:40 on September 11. Undoubtedly the first wave due to the failure of Derna dam and the largest wave due to the failure of the Abu Mansour dam, which was a devastating dam failure in Libyan history. The mode of failures could be a combination of hydraulic, seepage and structural. The overtopping is the main factor due to the huge amount of precipitation that is beyond the dams' capacities. However, other factors such as piping and foundation deficiency may play a significant role in the failure of both dams. Studies indicated that both Dams experienced fatal problems in the dam's bodies, and foundations. However, according to [11], and [12]. the clay core of the dams shows low plasticity so the clay sensitivity was low. [18], and [19] geotechnical investigation study of the Derna and Abu Mansur dams indicated that there are two zones of clay core, the upper (Fat Clay) and the lower (lean clay). Diversification of clay cores reported in both zones, also during their drilling program noted that the retrieved core was wet, soft and soaked clay. These phenomena can be caused by the difference of material composition, their compaction and fissures or joints in the main dam bodies. Also, the permeability test of the (clay core sample) of the dams ranged from 1.3 E-05 m/s to 8.9 E-09 m/s. However, they drilled in both dams to depths of 23m to 65m but did not reach the intact rocks at the foundation level to investigate the dam settlement. Reports of the General Water Authority (1995) and Stuck (2003, 2004) indicated that there are horizontal deformation and vertical settlement in both dams especially Abu Mansur dam Fig (3)

The failures of the Wadi Derna Dams are typical of the phenomenon of overtopping (spillway capacity or non-functioning floodgate). Other factors including internal erosion results from dangerous seepage of water (to the Dam core) by either cracking due to differential settlement and leakage either through the foundation/core contact plane.

However, all the studies [10-17], made a series of recommendations for urgent rehabilitation of both dams such as heightening of dams and increase the flood discharge capacity by new spillways in both dams but none of the recommendations performed.

[20] conducted a computer simulation of the Abu Mansour dam, examining both poorly maintained and well-maintained conditions. The results indicated that while the dam fails in both scenarios, the failure in the poorly maintained case occurs over a longer duration, thereby allowing individuals more time to evacuate.

The catastrophic failures of the Abu Mansour and Derna dams give imperative lessons to the Libyan and worldwide dam security to ensure the downstream communities and rethink of the dam safety.

4.0 Flood Frequency Analysis

Several approaches have been used in flood frequency analysis such as the California method, Hazen method, Gumbel method, Beard method, and Geological Survey method, [21]. We used the Geological Survey method that was adopted by Gumbel and by many adherents of his theories. [22], [23], [24].). The Ministries of Water Resources around the world and other organizations monitor the discharge (volume of water passing through a stream per unit of time) at gauging stations along the streams (Wadis).

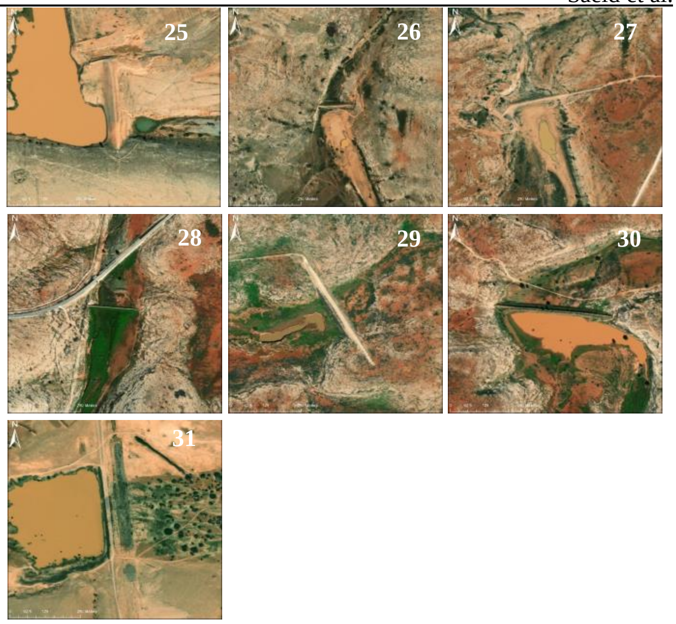

Fig (2) (continue) Satellites images for the Libyan dams. For the dam name and location, refer to Fig (1) and Table (1)

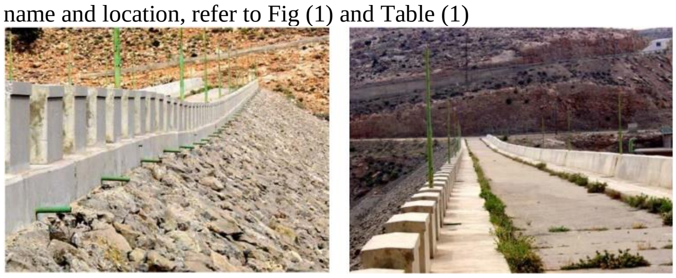

Fig. (3). Abu Mansour Dam vertical deformation as seen from the right abutment (A) and horizontal deformation as seen from the left abutment (B) after [11].

Table (2) General features of Abu Mansur and Derna dams.

Dam Criteria	Abu Mansour Dam	Derna Dam
Catchment Area	457 km^2	97 km^2
High of the Dam	50 m	40 m
Distance from the City	11 km	1 km
Storage million cubic meters	22.3 MCM	1.15 MCM
Spillway Capacity	170 m^3/s	350 m^3/s

This can be used to determine the frequency of flooding along the ephemeral stream. Estimates of flood frequency are more accurate with a long record (many years) of discharge records. The flood frequency is typically expressed as a recurrence interval. This is the average number of years expected between floods of a given magnitude, and it is calculated by listing all the floods that have ever occurred and ranking them from the largest to the smallest Table (3). The following table lists the largest discharges for 9 of the 12 years from 1-2 October 1959 to 11 April 1971 after [6], volume 1 (Flood protection of Derna Town).. The discharge data were scarce between 1959 to October 1967. The equation for recurrence interval is (Recurrence Interval = (n+1)/Rank). Where n = the number of years on record (in this case 11) and Rank = the position within that list.

Our approach to conduct a discharge-frequency curves were based on the methodology of the Geological Survey method to extend (extrapolate) the curve to estimate the 1000 years flood at cubic meters per second Fig (4). However, 1959 according to the record was a great flood felt by the population. Preliminary studies carried out in 1971 by Hidroprojekat revealed the following:

"there is no available data about the flood occurrences in the past; therefore, it is not known how frequent and strong the floods were. However, the local population still remembers the flood from 1959. We estimate the discharge amounted to 150 to 300 m3/s. However, this flood caused both human and material losses. The flood of 1959 probably initiated a considerable change in the strategies for the town's protection.

Based on flood recurrence intervals of Wadi Derna the 1000 years' flood was estimated between 580 to 1100 m3/s Fig (4).

[25] listed major flash floods that damaged the Derna city dating back to 1941 that caused significant losses for the German army. Other major flash floods occurred in 1956, 1959, and 1968. In September 2011 more than 15 Mm3 filled Abu Mansour dam. For now, we are excluding the years 1986, 2011, and 2023 from the calculations. It is evident that if we include the flash floods that occurred after the dam was constructed—particularly the significant events.

Table (3) The registered discharges through wadi Derna (October 1959 to 11 April 1971(, After [6] volume 1 (Flood protection of Derna Town). They estimated the maximum discharge of 1959 flood is about 400 m^3/s

Date	Rank	RI	Discharge m^3/s
26 October 1961			-
21 October 1965			
20-21 October 1967			
1-2 October 1959	1	12.0	450.0
20-21 October 1967	2	6.0	147.1
18-19 October 1969	3	4.0	77.6
12-13 January 1968	4	3.0	43.7
11-12 April 1971	5	2.4	37.8
25-26 October 1969	6	2.0	31.4
23-24 November 1971	7	1.7	12.1
26-27 October 1969	8	1.5	7.6
20-21 June 1971	9	1.3	6.1

in 1986, 2011, and 2023—Table (4) will not reflect the dam's initial design parameters. However, based on flood new recurrence intervals of Wadi Derna the 1000 years' flood estimated between 1700 to 2000 m3/s, Fig (5) which are above the design maximum flood estimated by [6] and the recalculated by [10-16].

The initial design of both dams was intended to be a 1,000-year return

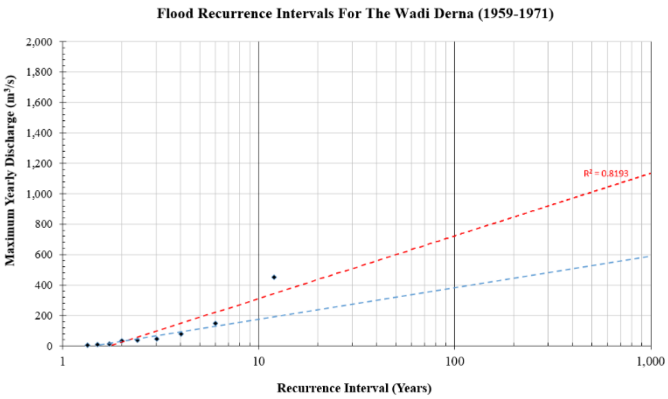

Fig (4) Flood recurrence intervals for the wadi Derna (October 1959 to 11 April 1971 (The blue and red lines are the lower and upper limits of the (extrapolated) curve to estimate the 1000 years flood at cubic meter per second.

time of design, which hampered statistical reliability. The predicted peak flows for a 1,000-year return period that were established as part of this study varied significantly from those that were done during the 2003 review study and initial design. (Table 5).

The flaws of the dam's design by [6-9] were initially due to the limited data of the wadi Derna discharge in that time. The 1972 study, which identified the primary hydrological events in Derna City (from 1959 to 1971), with the largest occurring in October 1959, served as the basis for the design (Fig 4, Table 3).

Table (4) The registered discharges through wadi Derna (October 1959 to 11 September 2023), The discharges (October 1959 to 11 April 1971), after [6]

Date	Rank	RI	Discharge m^3/s
10-11 Sep 2023	1	15.0	400-650
1-2 Oct 1959	2	7.5	450.0
28-29 Nov 1986	3	5.0	400
Sep 2011	4	3.75	300
20-21 Oct 1967	5	3.0	147.1
18-19 Oct 1969	6	2.5	77.6
12-13 Jan 1968	7	2.1	43.7
11-12 April 1971	8	1.9	37.8
25-26 Oct 1969	9	1.7	31.4
23-24 Nov 1971	10	1.5	12.1
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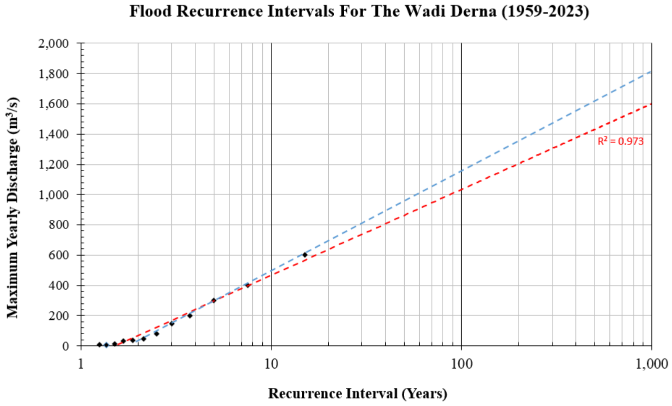

Fig (5) Flood recurrence intervals for the wadi Derna (October 1959 to 11 September 2023(The blue and red lines are the upper and lower limits of the (extrapolated) curve to estimate the 1000 years flood at cubic meter per second.

5.0 Discussion and Conclusions.

As we have seen, there are many problems in the dam's design by [6-9] due to the limited data of the wadi discharge. No emergency spillways in both dames.

The destructive Storm Daniel that struck northeastern Libya recently exceeded the rainfall's design capability of the dams. The World Weather Attribution [26] concluded that climate change is the mean reason for heavy rainfall in north-eastern Libya up to 50 times more likely to occur compared to a 1.2°C cooler climate. Because of the threat posed by climate change, we should routinely evaluate all of the dams in Libya. Additionally, the dams' long-term flows and rainfall should be re-evaluated, and the size of the spillways and gates should be confirmed to determine whether the structures could sustain more severe floods like Daniel or not. To deal with the climate changes we need new approaches to increase the safety of dams and downstream communities. The life cycle of the dams by US Army crop and ICOLD General Report [27] indicated that when the conditions change you need to re-engineering and evaluate the Infrastructure of the dam and re-design it Fig (6)

Table (5) Hydraulic design criteria related to flood protection for Derna and Abu Mansur Dams

Dam	Derna			Abu Mansur		
Study / Criteria	Original design (1972)	Stucky study (2003)	This study	Original design (1972)	Stucky study (2003)	This study
Return period (year)	1000	1000	1000	1000	1000	1000
Peak Flow (m3/s)	~ 500	906	1700	~600	1360	2000
Maximum released flow (m3/s)	350	570	670	170	420	1950

The probability of this type of 500-or 1000 floods are very low. However, it does not mean that a flood of that size occurs once every five hundred or a thousand years. So the probability (P) for any given recurrence interval (RI) is P =100 ÷ the RI. Therefore, the 500-years flood means that a flood of that size has a 0.2 % chance of occurring in any given year. The 1000-years flood means that a flood of that size has a 0.1 % chance of occurring in any given year and means that it is possible to have 1000-year floods in consecutive years [28]. The tragic failure of the dams in Wadi Derna happened due to

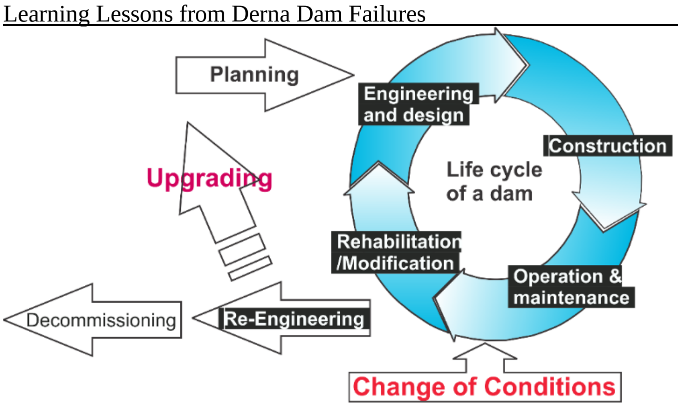

Fig (6) Life cycle of the dams by US Army crop modified after [31] and ICOLD General Report [27].

deficiency in the dams design and structures but what made it catastrophic is floodplain regulation. We need to recognize that the floodplain belongs to the river or seasonal wadi system, and any encroachment that reduces the cross-sectional area of the floodplain increases flooding. We should prohibit building in flood 2023 floodplain and use these areas for general public areas or recreation areas.

The failure of the Derna and Abu Mansour dams provides important lessons to improve the safety of dams in Libya (at least the 9 large Dams). We should evaluate all of the Libyan dams in terms of dam design, dam safety, and dam integrity to prevent such a tragic event from happening in Libya and worldwide. One of these lessons is reviewing the designed data, inspection and monitoring of dams as well as data analysis and interpretation that has a critical role in the field of dam safety. External and internal examination of dams during their lifetime. Routinely monitoring the deformation settlement, seepage, uplift, piezometric pressure and water level. In some cases, we need to monitor dam safety in real time as described by [29] and [30]

We should have early warning systems for natural disaster reduction. Mapping the flood hazards and risks (flood extend maps) in flood-prone areas (seasonal wadis), which will form the basis of future flood risk management plans.

6- Appendix

Table (1) Inventory of Libyan dams based on the reservoir design capacity from GWA (2012) and updated through remote sensing

7- Acknowledgement

We extend our gratitude to the Ministry of Water Resources, Benghazi, Libya, for their support. We also sincerely thank the anonymous reviewer for their valuable comments and suggestions.

8- References

[1]- Güven, A., & Aydemir, A. (2020). Risk Assessment of Dams. Springer Tracts in Civil Engineering. ISBN 978-3-030-47138-5 (Print), ISBN 978-3-030-47139-2 (eBook). https://doi.org/10.1007/978-3-030-47139-2

[2]- General Water Authority. (2012). Main dams in Libya. *General Dams Authority, dams brochure.* General Water Authority, Libya.

[3]- Ashoor, A., & Eladawy, A. (2024). Watch and Upgrade or Deconstruct and Relocate: Derna Catastrophe Lessons Amid the Climate-change Era of Unpredictable Flash Floods. *ResearchGate,* January 2024.

[4]- ICOLD. (2011). Constitution Statutes. *International Commission on Large Dams.* https://www.icold-cigb.org/userfiles/files/CIGB/INSTITUTIONAL_FILES/Constitution2011.pdf

[5]- ICOLD**.** (2024). World Register of Dams. *International Commission on Large Dams.* https://www.icold-cigb.org/GB/world_register/world_register_of_dams.asp

[6]- Hidroprojekat. (1971). *Wadi Derna Project: Volume 1: Flood Protection of Derna Town- Preliminary Design.*

[7]- Hidroprojekat (1972). *Wadi Derna Project: Volume 1.2.4: Water Discharge Structures- Calculations / Mansur Dam, Final Design.*

[8]- Hidroprojekat. (1972). *Wadi Derna Project: Hydraulic Model Studies, Derna Dam & Bu Mansur Dam, Final Design.*

[9]- Hidroprojekat. (1972). *Wadi Derna Project: Volume 1.2.5: Water Discharge Structures - Drawings / Mansur Dam, Final Design.*

[10]- Stucky. (2003). *Derna & Bu Mansur Reservoirs.*

[11]- Stucky**.** (2003). *Derna & Bu Mansur Dams Rehabilitation Project: Geotechnical Study / Bu Mansur Dam Perspective Design.* Stucky Consulting Engineers Ltd, Switzerland.

[12]- Stucky. (2003). *Derna & Bu Mansur Dams Rehabilitation Project: Geotechnical Study / Derna Dam Perspective Design.* Stucky Consulting Engineers Ltd, Switzerland.

[13]- Stucky. (2003). *Derna & Bu Mansur Dams Rehabilitation Project: Hydrology Report.* Stucky Consulting Engineers Ltd, Switzerland.

[14]- Stucky. (2003). *Derna & Bu Mansur Dams Rehabilitation Project: Solution Schemes – Report 1 / Flood Routing and Consequences on the Design of the Two Dams.* Stucky Consulting Engineers Ltd, Switzerland.

[15]- Stucky. (2003). *Derna & Bu Mansur Dams Rehabilitation Project: Solution Schemes – Report 2 / Derna Dam Perspective Design.* Stucky Consulting Engineers Ltd, Switzerland.

[16]- Stucky. (2003). *Derna & Bu Mansur Dams Rehabilitation Project: Solution Schemes – Report 3 / Bu Mansur Dam Perspective Design.* Stucky Consulting Engineers Ltd, Switzerland.

[17]- Stucky. (2004). *Derna & Bu Mansur Dams Rehabilitation Project: Geotechnical Final Report.*

[18]- Del Favero. (2002). Soil Classification Testing at Wadi Derna and Wadi Bumansur Dams, *Del Favero SpA Libyan Branch and Polservice Ltd,* Volume 1.

[19]- Del Favero. (2002). Soil Classification Testing at Wadi Derna and Wadi Bumansur Dams, *Del Favero SpA Libyan Branch and Polservice Ltd,* Volume 3.

[20]- Imran, J.; Nemnem, A.; Tanim, A.; Khan, S.; Nahian, A.; Goharian, E. Rising Waters, Falling Dams: Deciphering the Derna FloodDisaster. Nat. Portf. 2024, preprint version. https://doi.org/10.21203/rs.3.rs-3809203/v1.

[21]- Dalrymple, T**.** (1960). Flood Frequency Analysis. *Manual of Hydrology, Part 3, Flood-Flow Techniques: U.S. Geological Survey Water-Supply Paper 1543-A.*

[22]- Gumbel, E. J. (1945). Simplified plotting of statistical observations. *American Geophysical Union Transactions, 26,* 69–82.

[23]- Chow, V. T**.** (1953). Frequency analysis of hydrologic data with special application to rainfall intensities. *Illinois Univ. Bng. Bxpt. Sta. Bull.* 414.

[24]- Velz, C. J. (1950–51). Graphical approach to statistics. *Chicago, Water & Sewage Works,* 30 p. Reprinted 1952.

[25]- Ashoor, A**.** (2022). Estimation of the surface runoff depth of Wadi Derna Basin by integrating the geographic information systems and Soil Conservation Service (SCS-CN) model. *Sebha University Journal of Pure and Applied Sciences, 21*(2), 90–100. DOI: 10.51984/JOPAS.V21I2.2137

[26]- Zachariah, M., Kotroni, V., Kostas, L., Barnes, C., Kimutai, J., et al. (2023). Interplay of climate change-exacerbated rainfall, exposure, and vulnerability led to widespread impacts in the Mediterranean region. *World Weather Attribution (WWA).* https://spiral.imperial.ac.uk/bitstream/10044/1/106501/14/scientific%20report%20-%20Mediterranean%20floods.pdf

[27]- Williamson, T., Hughes, A., Hope, I., Mason, P., Bridle, R., Grubb, K., Tudor, S. (2015). Meeting Report: ICOLD Annual Meeting and Congress, Stavanger. *Dams and Reservoirs, 25*(3), 93–110. http://dx.doi.org/10.1680/jdare.16.00009

[28]- Keller, A. (2012). *Introduction to Environmental Geology* (5th ed.). Pearson Education, Inc. https://ia804507.us.archive.org/7/items/edward-a.-keller-introduction-to-environmental-geology-fifth-edition/%5BEdward_A._Keller%5D_Introduction_to_Environmental_Geology-Fifth%20Edition.pdf

[29]- Jeon, J., Lee, J., Shin, D., & Park, H. (2009). Development of dam safety management system. *Advances in Engineering Software, 40*(1), 554–563.

[30]- Li, B., Yang, J., & Hu, D. (2019). Dam monitoring data analysis methods: A literature review. *Structural Control and Health Monitoring.* https://doi.org/10.1002/stc.2501

[31]- Robert Taylor (2013). Dam Safety Program Management and Organization. *U.S. Army Corps of Engineers Great Lakes & Ohio*

River Division Dam Safety Workshop, Brasília, Brazil, 20–24 May.