THE WORKING GROUP ON LEVEES AND FLOOD DEFENCES UNDER THE EUROPEAN CLUB OF ICOLD

ISSUE 4 – July 2019

lfd-eurcold.irstea.fr

LEVEES Working Group Newsletter

Shaw Centre Ottawa, Conference centre where the ICOLD 2019 Annual Symposium was held.

A CALL FOR CONTRIBUTIONS

- *News, media or press releases on current storm events involving levees and flood defences.*
- *Current, ongoing or recently complete research projects with web links.*
- *Documents related to levees or flood defences: handbooks, guidance, reports and regulations.*
- *Information on events relating to levees or flood defences*
- *Links to informative/educational web sites and related organisations.*
- *Contact the WG – lfd-eurcold@irstea.fr*

Note from the Chairman

Rémy Tourment

This issue of our WG newsletter takes place between two ICOLD events in 2019: the Ottawa ICOLD meeting and the Crete EUCOLD symposium. Our LFD WG and the associated ICOLD LE TC had an important role in both these events. This issue will detail the activities of our groups, as well as other levee interesting information.

The TC 201 of ISSMGE on “Geotechnical Aspects of Dykes and Levees and Shore Protection” (see our previous newsletter) also actively participates to an important international event this year, the XVIIth European Conference on Soil Mechanics and Geotechnical Engineering (Reykjavik, Iceland, 1 - 6 September 2019). Some of our members have an active role as well.

Although these current events demonstrate the relevance of our activities, and our community dynamism, I have to share some disappointment with you.

First, despite many lobbying actions toward national committees and ICOLD board, the list of questions chosen for the Marseille 2021 congress unfortunately does not explicitly mention levees alongside with dams, even if some themes can relate to both types of works. Secondly, in this issue we do not have as much levee related information to share as in the previous one. We hope we will disseminate more information in the future: we count on every one of you to share information with the group, either through the newsletter or through the web site. This is an important objective, if not THE objective of our group!

On the plus side, to compensate the small number of articles related to levees in this issue, we have at the end and as a special feature a long and interesting article from the USA about this year’s floods on the Missouri river and the performance of levees.

Finally, we look forward to see you in Crete at the end of September.

Rémy Tourment

Co-cordinator of the EUCOLD LFD-WG and Chairman of the ICOLD LE TC

IN THIS ISSUE

Report on activities of ICOLD Technical Committee LE Levees

By Jonathan Simm, HR Wallingford

ICOLD TC LE (and its predecessor the EUCOLD WG LFD) has been working on two technical reports

1. An update of the **levee Inventory report.** The previous EUCOLD report on the situation with levees in various countries in Europe, plus USA (contributed by USSD) has been published and is now being updated with contributions from additional countries, new contributions already having been received from China and Norway. At the LE TC, a proposal was accepted from USSD to slightly extend each country chapter with a discussion of the role of risk informed decision-making

2. A **Dams and Levees inter-comparison report** designed to identify and describe the similarities and differences between dams and levees. The group preparing the report has also identified a number of ICOLD technical committees with which it would be useful to interact. Following an intermediate meeting in Paris, chapter leads for all chapters have been identified and the writing of the chapters is now progressing.

The motivation for both reports is to help to stress to ICOLD the importance of levees in the ICOLD member countries and the reasons for the dam and levee communities to interact.

In Ottawa, the ICOLD TC LE held a full day workshop on Monday 10th June, the first half of which was devoted to the Dams and levees inter-comparison report and the afternoon to interesting presentation updates, including a fascinating presentation from Germany on their approach to solving the problem of woody vegetation on levees. On the Tuesday 4th June, the ICOLD TC LE held its formal meeting, which was interspersed at lunchtime by a short meeting of the EUCOLD WG LFD. The main focus of the business was agreeing actions on the two reports. At the end of the meeting there was a short but interesting presentation from the new Chinese TC member on the issues with the 410,000 miles of levees in China.

Events of EUCOLD WG LFD at the 11th ICOLD European Club Symposium in Crete

By Patrik Peters

The Working Group on Levees and Flood Defences under the European Club of ICOLD (EUCOLD WG LFD) have a 2-day program organized which will consist of meetings, presentations and workshops.

Monday September 30th In the morning the second yearly Working Group meeting will be held. Besides informing and discussing about on-ongoing and planned activities, attendees can pitch state-of-the-art levee related projects taking place in their countries. In the afternoon a special session on the use of fibre optics for monitoring levee and dam behavior will take place. Up to five real-life cases from the levee and dam community will be presented focusing on the usability of outcomes and lessons learned to do this *at home*.
9:00-12:00/14:00-17:00

On **Tuesday October 1st** we invite you to join a whole day workshop considering similarities and differences between dams and levees. Through a series of steps, input will be provided to the dam/levee comparison report which will be published by the ICOLD Technical Committee on Levees.

9:00-12:00/14:00-17:00

Figure 1 - Minoa Palace Resort & Spa, venue for the 11th ICOLD European Club Symposium

ICOLD Ottawa meeting

List of technical presentations

- River Levee Failures in 2018 Japan Floods, by Hirotoshi Mori (Japan)
- The failure of the sand pit Cep inundation levee, by Jaromír Říha (Czech Republic)
- Tropical cyclones strike Mozambique: The case of Idai and Kenneth, by Elias Baptista (Mozambique)
- 2019 Missouri River floods and performance of levees, by Noah Vroman (USA)
- Woody vegetation on levees in Germany – Requirements, technical solutions and case studies, by Ronald Haselsteiner (Germany)
- Overview of levees on Yangtze River, China (15 min. presentation), by WU Aiqing (China)

A selection of oral presentations related to or interesting for levees in ICOLD Ottawa 2019

By Amir Farid Mojtahedi and Rémy Tourment

Directly linked to levees and flood risk management

- 134 - Canal Embankment Failure Mechanism, Breach Parameters and Outflow Predictions
- 220 - Hurricane Harvey rainfall, did it exceed PMP and what are the implications
- 281 - Conditional flood risk management
- 282 - Sensitivity of Probable Maximum Flood estimates: Climate change, modelling, and adaptation
- 362 - Investigation and assessment of interfaces with earthen levees
- 371 - Role of dams and levees in the flood risk management in Romania
- 411 - Feedback on lime / cement mixtures in the "deep soil mixing" screens of the Loire river levees
- 442 - ICOLD Bulletin 164 on internal erosion - how to estimate the loads causing internal erosion failures in earth dams and levees
- 537 - Levee and Dam breach Erosion through coarse grained materials

Interesting for levees and flood risk management

- 549 - Australian experience with application of Monte Carlo approach to extreme flood estimation
- 553 - Study of bank erosion and protection measures on Subansiri River, Assam, India
- 557 - Change in river basin morphology due to climate change led extreme flood event
- 28 - Earthquake-induced cracking evaluation of embankment dams
- 42 - Small embankment dams – benefits and problems
- 224 - Vegetation control on embankment dams as a part of remediation work
- 275 - Small historic dams made safe
- 416 - Small earth dam failure in Burkina Faso: the case of the Koumbri dam
- 577 - Fiber optic temperature sensors in under-documented dams

This selection is not exhaustive. Check the detailed program to make your selection.

All the papers related to these presentations, as well as the rest of the technical papers from Ottawa can be downloaded here : http://www.icold-cigb2019.ca/abstracts-and-technical-papers/technical-papers/

Partner seminars and workshops in ICOLD 2019 Ottawa meeting

On Friday 14th June, the last day of the Ottawa ICOLD 2019 meeting, 12 partner seminars were organized. Two of them are of particular relevance to our levees community.

In the morning, supported by ICOLD Committee E, Embankment Dams, ICOLD Committee LE, Levees, and Internal Erosion Working Group was held a seminar on « ICOLD Bulletin 164: Internal Erosion Workshop ». The following presentations were made :

- Intro on ICOLD Embankment Dams Committee, ICOLD IE Bulletin, EWGIE
- Overview of internal erosion mechanisms
- Developments in research and practice: a Canadian perspective
- Quantitative Risk Assessment for flood protection embankments using ICOLD Bulletin 164: the Symadrem experience
- Remediation against internal erosion through foundations – selection and installation of cut-off walls
- Backward Erosion Piping: a multi-scale investigation of a novel remediation technique
- Contact erosion detection and rehabilitation : a case study
- Hole Erosion Test: recent advances and use for assessing the safety of dikes and dams
- Levee failures and internal erosion mechanisms: the role of risk analysis
- An owner's view o assessing and managing internal erosion risk
- Using European research to investigate the potential for suffusion at a dam in Austria

The program and abstracts of this seminar can be found on our LFD WG web site : https://lfd-eurcold.irstea.fr/wp-content/uploads/2019/08/IE-Workshop-Presenters-and-Presentations.pdf

In the afternoon, a workshop was held to launch a new Working Group of the European Club of ICOLD, called International Working Group on Overflowing and Overtopping Erosion (IWGOOE).
The general objective of this working group is to help reduce the risk of failure of hydraulic structures, and the associated consequences, by overflowing and overtopping erosion all over the world. This general objective can be defined according to the following items:

- Sharing issues and problems to solve exposed by dam and levee owners, in all locations and load conditions (i.e. inland, fluvial and coastal);
- Sharing current state of practice and gaps in the toolbox available to practicing engineers;
- Sharing progress and advances from academic research and helping to pilot this research from the practitioner's perspectives and needs;
- Sharing the state of the art of the protection technology in order to increase the safety of dams and levees in overtopping scenarios;
- Facilitating international research collaboration to speed-up research progress and help dissemination of results.

The workshop was the occasion to discuss the themes of the WG in order to draft its Terms of Reference.

The full list if the partners seminars can be found here : http://www.icold-cigb2019.ca/partner-seminars/

ICOLD European Club - Working Group on Levees and Flood Defences

PROGRESS REPORT

June 2019

Prepared by Adrian Rushworth, Patrik Peeters and Rémy Tourment (chairman)

This Progress Report covers the period of July 2018 to June 2019.

The Working Group on Levees and Flood Defences of the European Club of ICOLD (EUCOLD LFD WG) was originally officially created on June 13 at the ICOLD 25th congress in Stavanger, Norway. Subsequently an ICOLD Technical Committee on Levees (ICOLD LE TC) was created during the ICOLD annual meeting in July 2017 in Prague. The intention of the LE TC includes continuation of the initial activities of the LFD WG. Therefore it was anticipated that the WG would disband after the ICOLD 26th Congress in Vienna. However, subsequent discussions identified benefits in continuing the WG and this view was strengthened by a SWOT-analysis prepared at a workshop in Aix-en-Provence.

Revised objectives and terms of reference have been prepared and were agreed at a meeting of the WG in Vienna. These terms of reference of the WG replace the initial ones from 2015.

The WG has the following summary objectives:

1. To act as the European level Backing Group to the new ICOLD TC on levees.
2. To provide a European Community of Practice on levees which will also act as a counterpart to the US Levee Safety Coalition.
3. To provide a vehicle for collation of issues for research and support for national and European level funding of such research.
4. To provide a vehicle for exchanging and disseminating news and views with regard to levee research and practice.

The new working group does not have fixed lifespan and membership will be open to all individuals approved by their National Committee. It can include more than one member from each country. The group will be led a coordinating team chosen for three years consisting of Rémy Tourment, Adrian Rushworth and Patrik Peeters for 2018-2021.

Since it was set up during 2015, the Working Group carried out an inventory of levees in the member countries. A report of the results was circulated and approved by the WG at the 26th Congress in Vienna 2018. It was also approved by the EURCOLD board at their meeting. An edited version has been prepared for dissemination with ISBN and DOI references (DOI citation: ICOLD European Club. EUROPEAN AND US LEVEES AND FLOOD DEFENCES/Characteristics, Risks and Governance. July 2018. ISBN 979-10-96371-08-2 - doi : 10.24346/cfbr_eurcold2018). This final version of the report is also available both on the CFBR (French National Committee) web site (as CFBR is the Editor) and on the Working Group web site. It has been sent to the EUCOLD Secretary to be added to the European Club web site, and also sent to ICOLD Central Office. The WG is considering how the inventory could be expanded to European countries not currently represented.

The WG had also commenced work on a dams and levees intercomparison report, identifying their similarities and differences. This work has been passed on to the new ICOLD TC for completion with the WG continuing to provide support. The WG supported the LE TC by participating in collaboration with their country's TC member at a workshop Paris in January 2019 on developing the dams-levees comparison.

The WG has continued to prepare and disseminate a newsletter with issue 3 published in April 2019 (newsletter past issues can be downloaded at https://lfd-eurcold.irstea.fr/index.php/wg-newsletter/). This issue included an explanation of the differences between the LE TC and the WG. New information continues to be added to the WG website (https://lfd-eurcold.irstea.fr).

Finally, one day of meetings (including a session on the use of fibre optics) together with one day of workshops on comparison of dams and levees will be organised at the 11th ICOLD European Club Symposium in Crete later this year.

Figure 2 - Members of the EUCOLD Levee Flood Defence Working Group and the ICOLD LE TC in Ottawa

UK Flood and coastal erosion risk management report: 1 April 2017 to 31 March 2018

By the Environment Agency

Summary of property flooding in England in 2017/2018

Between 1 April 2017 and 31 March 2018 a total of 667 properties were flooded. There was low flood risk until the summer storm season began at the end of May. From July there were several summer storms, including 4 notable floods where communities were flooded. The table shows the notable floods from 1 April 2017 to 31 March 2018. The rest of the properties flooded were due to a number of smaller floods.

Table 1: notable floods from 1 April 2017 to 31 March 2018

Location of flood	Date	Number of properties flooded
Coverack, Cornwall	14 July 2017	50
Scarborough, Yorkshire	22 to 24 August 2017	60
Millom, Cumbria	30 September 2017	200
Storm Brian	End of October 2017	49
Galgate, Lancashire	23 November 2017	225

UPCOMING EVENTS

https://lfd-eurcold.irstea.fr/index.php/events/

2019

- 4.-5 September 2019. **DWA-Levee-day** in Koblenz (Germany) on Rhine
  NB: the language of the event is German
- 1-6 Sept 2019, The XVII **European Conference on Soil Mechanics and Geotechnical Engineering** in Reykjavik (Iceland). Includes a session on dikes and levees. Also includes a workshop of ISSMGE TC201 on September 1st. http://www.ecsmge-2019.com
- 2-4 Oct 2019, **European Club Symposium Crete, abstract deadline is 18/02/2019**, See the announcement on http://cnpgb.apambiente.pt/IcoldClub/index.htm
- 9-12 Oct 2019, **Combined NZSOLD / ANCOLD technical workshop and conference** in October in Auckland (New Zealand). See: https://nzsoldancold2019.co.nz/speaker/
- Workshop of ISSMGE TC 201 on November 20th 2019 in Cancun Mexico, part of the **PanAmerican conference on soil mechanics and geotechnical engineering** http://panamerican2019mexico.com/panamerican/

2020

- April 2020 **Annual Meeting of ICOLD in New Delhi** (India)
- Workshop of ISSMGE TC 201 on November 20th 2019 in Cancun Mexico, part of the **PanAmerican conference on soil mechanics and geotechnical engineering** http://panamerican2019mexico.com/panamerican/

2021

- ICOLD Congress in Marseille (France) 27th Congress – 89th Annual Meeting http://cigb-icold2021.fr/en/

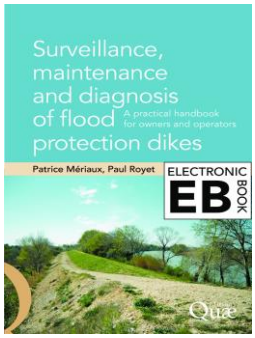
LEVEE RELATED DOCOUMENTS

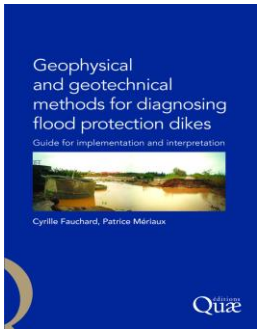
Books and Reports

- Report on "European and US Levees and Flood Defences – Characteristics, Risks and Governance" – Final version
  ICOLD European Club. *EUROPEAN AND US LEVEES AND FLOOD DEFENCES/Characteristics, Risks and Governance*. July 2018. ISBN 979-10-96371-08-2 – doi : 10.24346/cfbr_eurcold2018
- From Japan: Keep in mind ～How we responded to "the heavy rain disaster in July 2018"～
  http://www.cgr.mlit.go.jp/photo/h3007gouu_kiroku/kioku_english.htm
- The report which summarizes Dutch Flood Risk Management policy is Fundamentals of Flood Protection:
  https://www.enwinfo.nl/images/pdf/Grondslagen/GrondslagenEN-lowresspread3-v.3.pdf

Two books about levees are now free in electronic format (epub and PDF

- https://www.quae.com/produit/91/9782759212736/geophysical-and-geotechnical-methods-for-diagnosing-flood-protection-dikes
- https://www.quae.com/produit/96/9782759215386/surveillance-maintenance-and-diagnosis-of-flood-protection-dikes





Papers

- **Reliability-based partial factors for flood defenses**
  By : R.B.Jongejan F.Diermanse W.Kanning M.Bottema
  https://doi.org/10.1016/j.ress.2019.106589
- From Canada: **Guidelines for the design, construction, and rehabilitation of coastal and estuarine dykes in New Brunswick and Nova Scotia**
- **Impact of animal burrows on earthen levee body vulnerability to seepage**, Michela Rosa Palladino, Silvia Barbetta, Stefania Camici, Pierluigi Claps, Tommaso Moramarco
  e12559 | First Published: 08 August 2019
  https://onlinelibrary.wiley.com/doi/full/10.1111/jfr3.12559
- The book of abstracts of Digues 2019, a conference on levees, held in Aix en Provence includes English abstracts of the 77 papers. It can be downloaded here: https://lfd-eurcold.irstea.fr/index.php/levees-related-documents/ Full papers (in French) are also available with DOI links found in the book.

Special feature!

PERFORMANCE OF LEVEES DURING THE 2019 MISSOURI RIVER FLOOD EVENT

Noah D. Vroman (1), Emily K. Calla (2) , and Jennifer L. Wood (3)

Introduction

The Missouri river is the longest river in North America at approximately 3,647 km (2,341 miles) in length. The Missouri River basin (Figure 1) consist of a sparsely populated, semi-arid watershed of more than 1.3 million square kilometers (500,000 square miles) that includes parts of ten states in United States of America (USA) and two Canadian provinces. Based on information with the U.S. National Levee Database (https://levees.sec.usace.army.mil/#/), within the Missouri River basin, there are over 800 levee systems totaling over 2,500 miles in length. These levee systems contain over 425,000 people who live and work behind the levee and $70 billion in U.S. dollars in property value that rely on the levee to reduce flood risk. Many of these levee systems were constructed in the late 1950's through the early 1960's and have been providing flood risk reduction benefits to communities, commercial businesses, industry, and agriculture for over 50 years.

Figure 1. Illustration of the Missouri River Basin Located in the United States of America [Source U.S. Army Corps of Engineers].

(1) U.S. Army Corps of Engineers, Levee Safety Center, Vicksburg, Ms
(2) U.S. Army Corps of Engineers, Risk Management Center, Pittsburgh, Pa
(3) U.S. Army Corps of Engineers, Kansas City District, Kansas City, Mo

Two major flood events occurred along the lower portion of the Missouri River basin in 2019 – a major flood event during March 2019 and a major flood event during May 2019. These flood events set new flood records along the lower Missouri River and greatly exceeded the capacity of many levee systems along the lower Missouri River basin causing over 100 levee systems to overtop and over 30 levee systems to breach due to overtopping. Many of the levee systems that breached experienced multiple breaches, with nearly 130 levee breaches. Recovery efforts continue today and will continue for months to come. Over 700 miles of levees were damaged, the impacts from the spring flood events will likely increase as damage assessments are incomplete for many systems due to inundation.

This article summarizes the flood event that occurred including the performance levees and recovery efforts underway.

March 2019 - Flood Event and Levee Performance

Weather events occurring in the Missouri River basin starting back in the fall of 2018 through the spring of 2019 led to an extreme and devastating flood even on the Missouri River and its tributaries. Wet weather in the fall of 2018 led to high soil moisture throughout the area. In the winter of 2019, there was extraordinary cold temperatures that cause significant frost depths and thick river ice. In beginning of March 2019, there was 2.5 to 7.7 cm (1 in to 3 in) of equivalent snow water across the lower portion of the basin including western Iowa, southern South Dakota, and eastern Nebraska. During week of 11 March 2019, temperatures drastically warmed with daily highs reaching 5 °C to 15°C (40 °F to 60°F) and 2.5 to 10 cm (1 in to 4 in) of rainfall occurred in the area. The water control reservoirs (e.g. dams) in the upper Missouri River basin had capacity to capture snowmelt. However the flood event was caused by rainfall over areas without reservoirs. The rain on snow melt created flash flooding with very little warning.
During the week of 14 March 2019, 45 river gages recorded new records along the lower river basin as shown in Figure 2. In many areas along this stretch of the Missouri River, gages exceeded records by almost a meter as shown in Figure 3, which the river stage exceeded the previous record set in 2011 at Nebraska City, NE by 0.60 m (2 feet). As shown in Figure 3, the lower Missouri River stage increased from a moderate flood stage to a major flood stage in approximately twelve hours. The river at the Nebraska City gage was above the previous record set in 2011 for almost four days. In many locations, overtopping of levees occurred over multiple days.

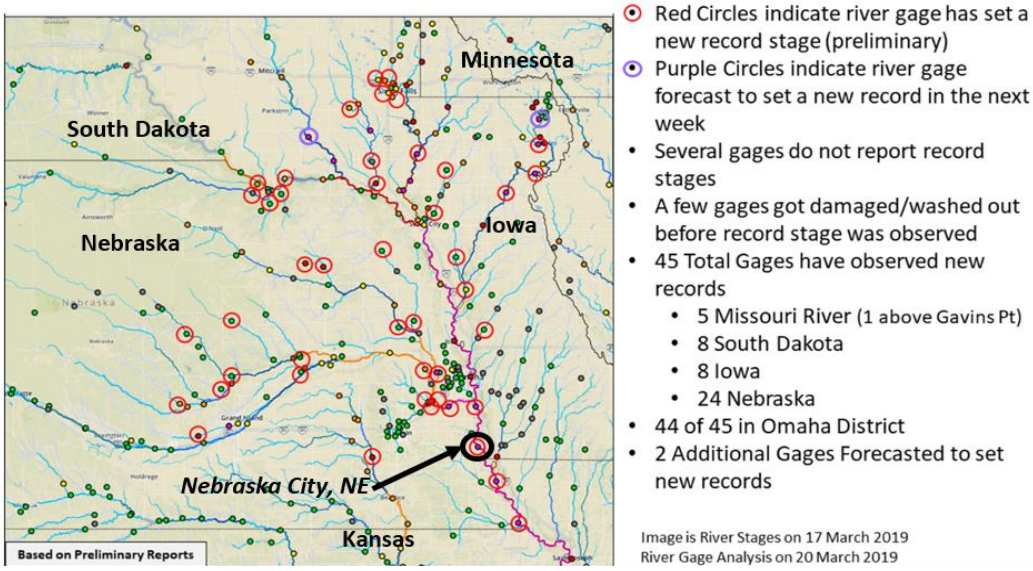


Figure 2. 20 March 2019 River Gage Analysis Showing Gages That Have or Will Reach Record Stages Along the Lower Missouri River Basin [Source U.S. Army Corps of Engineers].

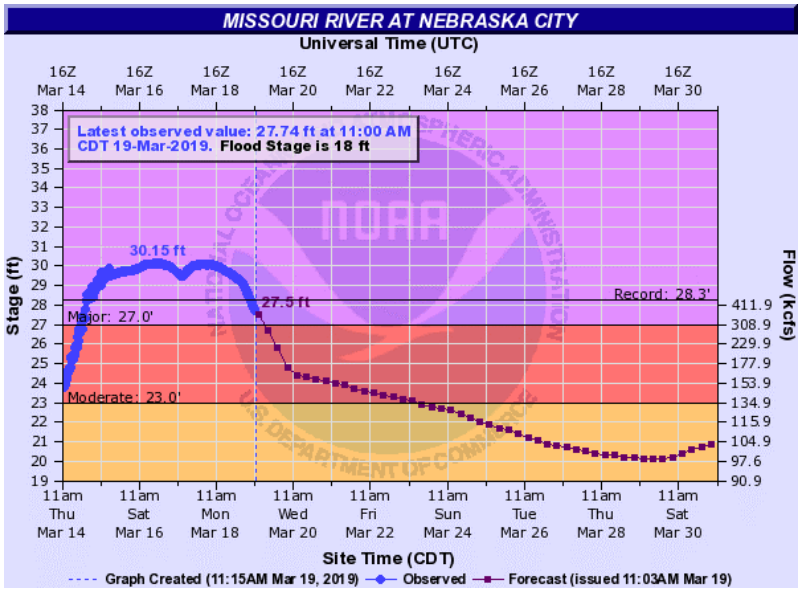


Figure 3. Missouri River Stage at the Nebraska City, NE Gage on 19 March 2019 [Source National Oceanic and Atmospheric Administration].

These record setting water surface elevations resulted in numerous levee systems overtopping by a rush of water and several of the overtopped levee systems breaching and many more experiencing erosion damage. Levee systems that overtopped are estimated to have incipient overtopping at an annual chance of exceedance (ACE) of 1 in 500 or greater. As shown on Figure 4, levee overtopping and over forty levee breaches (caused by overtopping) flooded approximately 780 sq km (301 sq miles) of land within the U.S. Army Corps of Engineers (USACE) Omaha District. In the Kansas City District, located just downstream of the Omaha District along the lower Missouri River basin, experienced overtopping of fourteen levees in which eleven of those levees eventually breached due to overtopping. Figure 6 shows pictures of levee overtopping and levee breached due to overtopping in northern Missouri along the river.

Some of the impacts of the flooding include U.S. Interstate Highway I-29 closures (shown in Figure 4 and Figure 5), community evacuations and flooding, and flooding of thousands of acres of farmland. As the crest of the event moved downstream, many levee owner and operators with the support of USACE, actively flood fought the high water and were able to prevent overtopping on many systems on the lower Missouri River. Levees that did not overtop still were monitored very closely and many had issues with seepage and surface erosion. Figure 6 shows pictures of levee overtopping and levee breached due to overtopping in northern Missouri along the river.

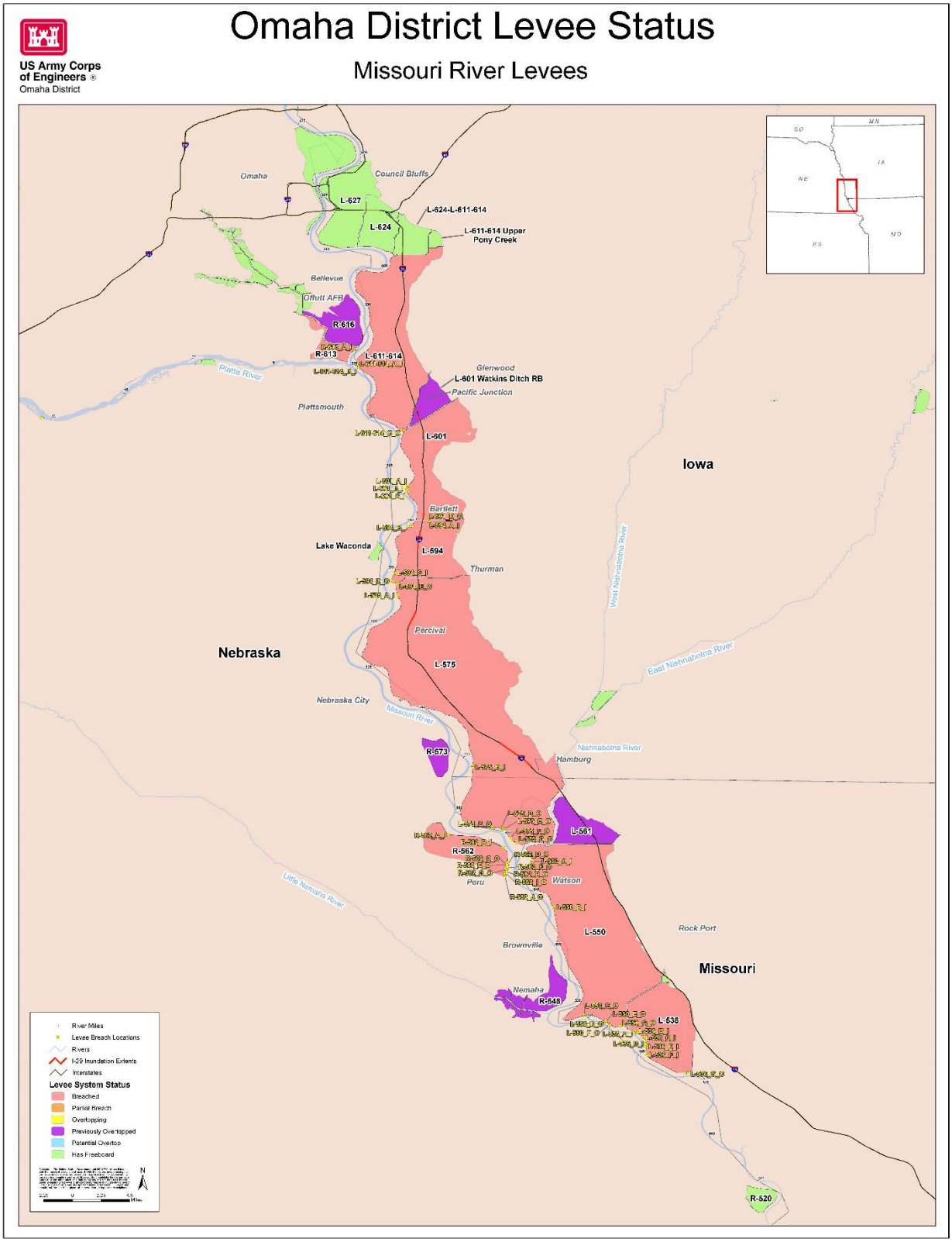


Figure 4. 25 March 2019 Map Showing Leveed Areas of Overtopped and Breach Levees within the U.S. Army Corps of Engineers, Omaha District [Source U.S. Army Corps of Engineers].

Figure 5. Picture Taken in March 2019 Showing Flooding Along U.S. Interstate Highway I-19 Near Nebraska City, NE [Source U.S. Army Corps of Engineers].

Figure 6. Picture Taken of a Levee Overtopping (Left) and a Levee Breached Due to Overtopping (Right) [Source U.S. Army Corps of Engineers].

May 2019 - Flood Event and Levee Performance

Multiple rainfall events in May and June have occurred in the central part of the country inundating areas with already saturated ground. New record and near record river levels occurred once again in the lower Missouri River basin. The period from 23 April 2019 to 22 May 2019 was the wettest from 131 years of rainfall recordings at Kansas City International Airport located in Kansas City, Missouri. Much of Kansas and western Missouri saw 25 to 50 cm (10 to 20 inch) of rain in that 30 day period which is three to five times normal. This record late spring rainfall resulted in devastating flooding eastward of Kansas City, Missouri.

During this event fifty levees overtopped and at least half of these levees subsequently breached (however the total number is still yet to be determined). There have been no lives lost reported due to overtopped or breached levees. However almost 2,500 people live and work behind these overtopped levees. The property value estimates behind these levees are around $290 billion in U.S. dollars, which does not include significant agricultural damages. Levees that were not overtopped have significant amounts of rain water and interior drainage ponded on the landside because of the remaining high river levels and above average releases from upstream dams.

Post Flood Event Recovery

The 2019 historic flood event within the Missouri River basin exceeded the height of many levees along the lower Missouri River. While many levees were overtopped and breached, community evacuations and flood-fight efforts helped to reduce consequences from this extreme event. One of the biggest successes noted to date during after flood event was to have USACE staff in the field on the levees helping levee owners and operators monitor levees and provide technical assistance and best practices for flood-fighting. USACE teams were deployed to all of levee constructed by USACE that were significantly impacted. These teams were a mix of experienced flood fighting personnel and those with little to no experience. The Survey 123 app (https://survey123.arcgis.com/) was used by the USACE field teams during both events and was extremely successful in tracking levee performance during and after the event.

In total, over 100 levee systems were overtopped and over 30 systems experienced a breach. Many of the systems that breached experienced multiple breaches, with nearly 130 breaches. Recovery efforts continue today and will continue for months to come. There has been progress made in setting initial breach closures on levee systems within the Omaha District as shown in Figure 7 and 8 below. In Figure 7, the levee height is approximately 2.1 m (7ft), breach width is nearly 79.2 m (260 ft), and breach depth is roughly 7.6 m (25ft). In Figure 8, the levee height is approximately 3.3 m (11ft), breach width is nearly 350 m (1,150 ft), and breach depth is roughly 20 m (65ft).

Over 700 miles of levees were damaged, the impacts from the spring flood events will likely increase as damage assessments are incomplete for many systems due to inundation. Preliminary estimates indicate that levee repair costs could be $1 billion in U.S. dollars. These levees have provided flood risk reduction benefits to communities, industry, commercial businesses, and agriculture for over 50 years. Restoring the levees to continue to provide flood risk reduction benefits is a priority.

Figure 7. Initial Levee Breach Closure in Omaha District on 24 March 2019 [Source U.S. Army Corps of Engineers].

Figure 8. Initial L611-614 Levee Breach Closure in Omaha District on 12 June 2019 [Source U.S. Army Corps of Engineers].