LLOYD'S

RISKS

LLOYD'S EMERGING RISKS TEAM REPORT

THE HERBERT HOOVER DIKE

A DISCUSSION OF THE VULNERABILITY OF LAKE OKEECHOBEE TO LEVEE FAILURE; CAUSE, EFFECT AND THE FUTURE

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EXECUTIVE SUMMARY

1 Hurricane Katrina caused wide-scale damage to the Louisiana coast and New Orleans in particular, (Lloyd's share was USD 3.4bn). However, there are other less well-known areas that are also extremely vulnerable to hurricanes.
Lake Okeechobee in Florida is ranked second by the International Hurricane Research Center in a list of the most vulnerable US mainland areas to hurricanes.

2 A report was commissioned by the South Florida Water Management District in 2006 to review the stability and safety of the Herbert Hoover Dike around Lake Okeechobee.
Report concludes "The current condition of Herbert Hoover poses a grave and imminent danger… … [The dyke] needs to be fixed. We can only add that it needs to be fixed now, and it needs to be fixed right. We firmly believe that the region's future depends on it."

3 A separate report also concludes that the dyke is vulnerable to failure caused by water seepage and piping at high water levels, whether this high water level is produced by long-term changes in rainfall or by hurricane events.
The findings from the research led to the re-evaluation of the design of the dyke improvements which the US Army Corps of Engineers had begun to implement.

4 Work on the first three sections is expected to last for five years and until this repair work is completed, the risk levels associated with the Herbert Hoover Dike are elevated.
Insurers should be aware of research papers, such as those reviewed in this report and scientific advances, particularly with regard to climate change to factor forecasts when pricing catastrophe exposed risks in Southern Florida.

Catastrophe models, in general, do not model levee failure. Insurers must be aware of all possible sources of potential loss when pricing risks and evaluating capital requirements.

5 As well as the total of 40,000 residents whose houses and lives would obviously be in serious danger, there could be far-reaching effects for the whole of southern Florida should the Herbert Hoover Dike fail.
The three counties to the immediate south-east of Lake Okeechobee have a combined population in excess of 5 million residents.

Recovery could take years, with economic losses likely to run to the tens of billions of dollars. This would be in addition to any related wind losses which are also likely to be measured in billions.

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PURPOSE

THIS IS THE FIRST REPORT WRITTEN BY THE NEW LLOYD'S EMERGING RISKS TEAM

This is the first report written by the new Lloyd's Emerging Risks team, which is part of Lloyd's Franchise Performance Directorate (FPD).

Our definition of an *emerging risk* is a risk which is in the process of being understood and evaluated. As well as informing the market about these risks, this team also wishes to highlight risks which may have been either ignored or misunderstood in the past and should, we believe, be incorporated when pricing risks or assessing capital requirements.

2004 and 2005 were record breaking years for insurance industry losses. Insurers *must* ensure that all risks are priced correctly and take into account all factors which can impact on potential losses. Many insurers will be doing this already, however, lessons can be learnt from the hurricanes of recent years and mistakes can be avoided. Users of catastrophe models must be aware that models are not a panacea. The understanding of the limitations of any model or tool is a prerequisite for its proper usage.

The purpose of this report is to highlight a specific area in Florida which has been impacted with catastrophic consequences in the past and explain the reasons why this territory poses a significant level of risk.

Because we believe the potential for catastrophe in this region may not be fully accounted for by all insurers, in either the modelling or pricing of potentially affected policies, we have decided to make this the focus of the first Lloyd's Emerging Risk team's report.

BACKGROUND

The devastation caused by flooding in New Orleans from Hurricane Katrina in August 2005 is still fresh in the memory. Rebuilding and recovery from the disaster is likely to take several years and life may never be the same for many residents of the "Big Easy".

Although the insurance industry suffered unprecedented losses when Hurricane Katrina caused wide-scale damage to the Gulf coast, New Orleans in particular, (Lloyd's share was USD 3.4bn) there are other less well-known areas that are also extremely vulnerable to hurricanes.

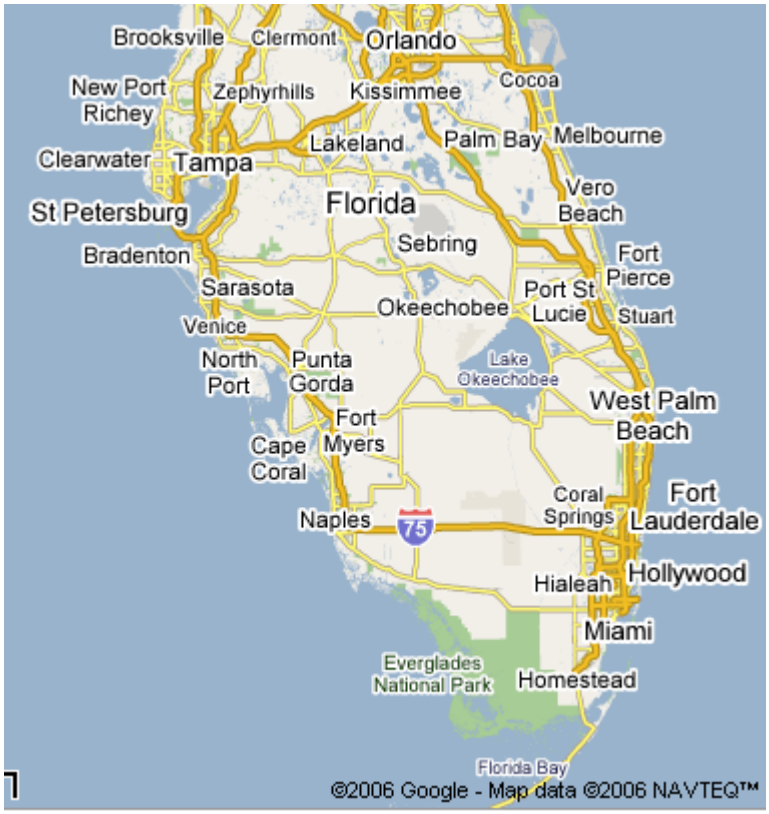
The International Hurricane Research Center at Florida International University in Miami has released the top ten most vulnerable US mainland areas to hurricanes, based upon twelve criteria. The rankings are as follows:

1. New Orleans, Louisiana
2. Lake Okeechobee, Florida
3. Florida Keys
4. Coastal Mississippi
5. Miami/Ft. Lauderdale, Florida
6. Galveston/Houston, Texas
7. Cape Hatteras, North Carolina
8. Eastern Long Island, New York
9. Wilmington, North Carolina
10. Tampa/St. Petersburg, Florida

Perhaps it is not surprising to see that New Orleans is at the top of the list. However, the second most vulnerable area is one that is probably not so well known.

Lake Okeechobee

Lake Okeechobee can be found in the middle of southern Florida and extends about 35 miles north to south and 30 miles east to west, covering an area of approximately 730 square miles. The lake is shallow; the average depth at normal water levels is 10 feet.



South Florida Water Management District Report (2006)

On 11 January 2006, the Governing Board of the South Florida Water Management District (SFWMD) commissioned an independent technical review of the stability and safety of the Herbert Hoover Dike around Lake Okeechobee. The review was conducted by an expert review panel comprising of three professional engineers; Dr Les Bromwell, Dr Robert Dean and Steven Vick.

As a result of the review, a report was written titled “Report of Expert Review Panel, Technical Evaluation of Herbert Hoover Dike, Lake Okeechobee, Florida.

The Report of the Expert Review Panel can be found here:

Report of Expert Review Panel

This Lloyd’s Emerging Risks article relies on some of the maps and images which can be found in the Expert Review Panel Report and a subsequent presentation which also resulted from the technical review.

This Lloyd's article discusses the findings of this review and looks at the potential implications of these findings for insurers.

HERBERT HOOVER DIKE

Historical hurricane events

The 1926 Miami Hurricane made landfall as a Category 4 hurricane and caused high storm-surge on Lake Okeechobee which breached a small levee on the west side of the lake, causing the deaths of 386 people.

However, just two years later, the 1928 Hurricane was to cause even greater damage and fatalities. The first ever recorded Category 5 hurricane in the Atlantic basin had already wreaked havoc in the Caribbean before making landfall in southern Florida.

When the storm hit the lake, a small dyke at the south of the lake was breached. The resulting flood was large; an area of hundreds of square miles was affected. Many houses were knocked off of their foundations and broke into pieces against any obstacle that they floated into. The latter part of the storm caused the flood to reverse itself and the small levee at the northern part of the lake was also toppled causing more flooding.

IN THE 1928 HURRICANE, HALF OF THE PEOPLE WHO LIVED AROUND THE LAKE PERISHED

It is thought that up to 3,000 people, some half of the population who lived around the lake perished; the vast majority of which died as a direct result of the flooding of Lake Okeechobee. Only the Galveston Hurricane of 1900 is known to have caused more deaths from a natural disaster in the United States.

These hurricanes set the stage for the construction of the Herbert Hoover Dike by the U.S. Army Corps of Engineers.

The history of the Herbert Hoover Dike

As a result of the hurricanes in 1926 and 1928, the first part of a new levee was constructed between 1932 and 1938 on the south side of the lake approximately 70 miles long and on the north side approximately 16 miles long.

After the 1947 Fort Lauderdale Hurricane caused flooding, again on the south side of the lake, the "Central and South Florida Flood Control Project" was set up to build extra canals and levees. The project was managed by both the US Army Corps and the newly created SFWMD.

Under the auspices of the new management, the Herbert Hoover Dike was built around the full circumference of the lake and this work was completed in the 1960's.

Interpretations of key words:

A *levee* retains water temporarily during times of potential flooding

A *dam* retains a permanent storage pool creating a reservoir

A *dike* is a generic term for any embankment that controls or confines water.

The Herbert Hoover Dike was built as a levee to protect the local area from hurricane-related flooding. It is made entirely from earth dredged up from around the lake and assembled into a huge mound.

The average height of the dyke is 35 feet. Steepness of lakeside slopes vary between 10% and 33% and between 20% and 50% on the outer or landside slopes.

*Source: The Jacksonville District, U.S. Army Corps of Engineers (*www.saj.usace.army.mil)

Water Management Project

As a result of the steady increase in agriculture, coupled with a large increase in the population of southern Florida, the water management project moved beyond flood prevention to include water supply and drainage.

The U.S. Army Corps built a canal which causes the water to flow more quickly down the Kissimmee River. The water level in Lake Okeechobee is then managed by releasing water to canals connected to rivers flowing into both the Gulf of Mexico and the Atlantic. Water is also directed to populated areas in the south east of Florida rather than through the natural route to the Everglades and Florida Bay.

POTENTIAL FOR DIKE FAILURE

In the 1970's, the decision was taken to increase the upper limit of water in the lake from 15.5 feet to 17.5 feet.

And this brings us to the key concern; the dyke is no longer being used solely as a levee to protect the area from flooding when storms are in the vicinity but also to hold a permanent reserve of water. The lake is being used as a reservoir and therefore the dyke is now operating as a dam.

This means that water is pushing against the dyke nearly all of the time and that the risk does not come solely from a hurricane event. The dyke must act like a normal reservoir, i.e. be able to safely store floodwaters without overtopping.

The dyke was built from un-compacted earth, made up of naturally porous materials such as peat, gravel, sand and shell and is therefore prone to leaks. Since the construction of the dyke, the land outside of the dyke has been eroding, particularly on the south side of the lake.

The Herbert Hoover Dike, when built, was never intended to be used in this way and it has only recently been designated to be a dam. The flood criterion for dams is far more stringent than that which it has previously been subject to and also to which it is currently able to meet.

In their Expert Review Panel Report, prepared for the South Florida Water Management District in 2006, Bromwell, Dean and Vick describe the basic problem facing the dyke to be "simple". They say:

THE DIKE HAS NARROWLY ESCAPED FAILURE ON SEVERAL OCCASIONS

"Certain geologic formations that underlie the dyke, and portions of the material that comprise it, bear a striking resemblance to Swiss cheese. Laced with interconnected voids and open channels, not only do these materials conduct large flows of water, they also admit sand and silt-sized soil particles that comprise the bulk of the dyke and its foundation. In a process of unstable feedback called internal erosion or piping, this seepage causes more particles to be removed, which in turn causes more seepage. Eventually, either excessive water pressures cause the dyke slopes to fail, or the dyke simply collapses from the net effect of particle removal one grain at a time. Herbert Hoover Dike has narrowly escaped failure from this process on several occasions and we suspect that its condition may be worsening."

The situation is exacerbated by the erosion of the land outside of the lake. In this respect Bromwell commented to the Floridian press:

"The important factor is the seeping going from the lake to the land side. The lower the land side, the greater the difference and the greater the seeping is."

Consequences of dyke failure

The Expert Review Panel Report concludes that failure of the Herbert Hoover Dike would be disastrous.

As previously mentioned, the 1928 hurricane is thought to have been responsible for the deaths of half of the local population.

Now there are approximately 40,000 people who live within the immediate vicinity of the lake. Should the dyke fail, whether this is due to pressure from hurricane-related storm-surge or because of the inherent weaknesses in the dyke discussed above, this is likely to cause a large number of deaths and destroy many thousands of homes.

Likelihood of dyke failure

> *"The current condition of Herbert Hoover Dike poses a grave and imminent danger… … [The dike] needs to be fixed. We can only add that it needs to be fixed now, and it needs to be fixed right. We firmly believe that the region's future depends on it."*
>
> *Source: Report of Expert Review Panel*

As the quotes above clearly show, the Expert Review Panel Report concludes that there is a high likelihood of dyke failure.

This likelihood is strongly correlated with the amount of water in the lake.

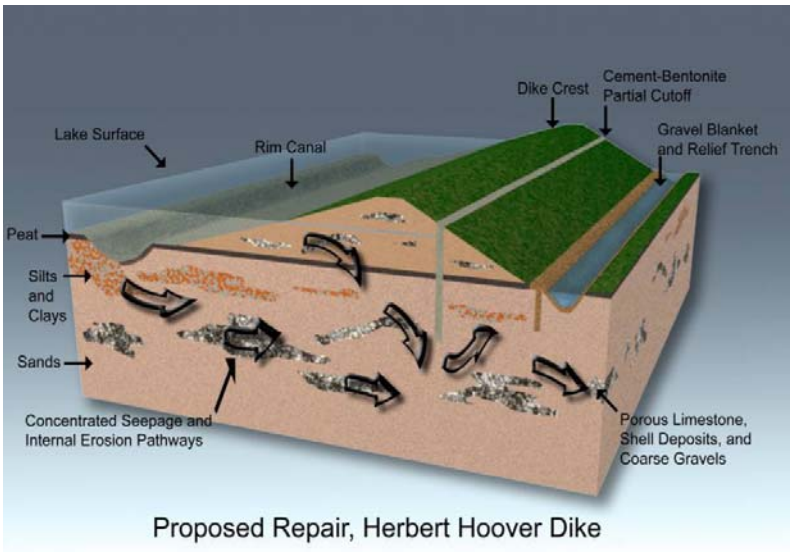
Past events, which have caused the water level to be high, have damaged the dyke through internal erosion. The dyke has not been able to sustain itself as the US Army Corps of Engineers has had to perform remedial repairs on more than one occasion, a situation which cannot be considered a long-term solution.

In fact, the US Army Corps of Engineers have carried out their own probabilistic assessments which have concluded that without their intervention, the probability of failure is approximately a one in **six** chance in any year.

Criticism of repair plans

At the time of writing the Expert Panel Review Report, a repair plan had already been initiated. However, the report raises concerns about these repair plans – and in light of these, the plan was suspended.

The repair consisted of building what is known as a “cutoff” wall through the landside or “downstream” slope of the dyke. The wall is made of cement and would penetrate part of the way into the foundation. There would also be a “gravel blanket” and relief trench at the bottom of the downstream slope. A diagram of the proposed repair is shown below:



Source: Report of Expert Review Panel

The report has three main criticisms of this repair plan; firstly because the cutoff wall would penetrate only a part of the way into the foundation it would not block any internal erosion beneath it. Secondly, Bromwell, Dean and Vick are of the opinion that it would actually support seepage and instability of the downstream slope when lake levels rise above it. Finally, their analyses suggest that there would possibly be instability within the dyke during the building of the wall and trench.

Recommendations

The recommendations from the Expert Review Panel Report are summarised below:

1 Reduce the probability of high lake levels by reducing the water level in the lake by two feet until effective repairs are made.

2 Flood and hurricane evaluations should be initiated as soon as possible. The relevant safety criteria that Herbert Hoover Dike will be expected to meet now that it has been designated as a dam should be incorporated as well as the most up to date hurricane data.

3 Because of the length of time that it will take to repair the dam, it is possible that the dam will fail before the reparation is completed. Therefore, the Emergency Action Plan should be reviewed and updated.

4 Re-evaluate the current design of repairs. The depth of the cutoff wall should be extended and should not be built on or through the downstream slope. Also more thought should be given to ensure the integrity of the dyke during the construction of the wall and trench.

Further research – International Hurricane Research Center Report

A separate report by Zeng, Xiao and Leatherman produced for the International Hurricane Research Center (IHRC), was published in 2006. This research looked at what would happen at Lake Okeechobee today should either the 1928 or 1949 hurricanes be repeated as well as looking at a further two hypothetical scenarios.

The IHRC report states that it is likely that the breaching of some of the levees in New Orleans during Hurricane Katrina was caused by stability failure of foundation soils beneath the earthen base similar to those discussed as being the main source of the vulnerability of Herbert Hoover Dike.

The Coastal, Estuarine and Storm Tide (CEST) model is the numerical simulation model[1] developed by the IHRC for storm surge simulation. The model is driven by atmospheric pressure, surface wind and tide.

In addition to modelling the two historical storms, the hypothetical hurricanes were generated by shifting and rotating the tracks of Hurricane Katrina and Wilma so that they made landfall on the East coast of Florida and passed along the northern side of Lake Okeechobee. The event parameters were based upon those of Hurricane Katrina for the Gulf coast and upon Hurricane Wilma as the storm lingered over the Yucatan Peninsula of Mexico where it dropped between 12 and 16 inches of rain.

IHRC Conclusions

The report states that the dyke is vulnerable to failure caused by water seepage and piping at high water levels whether this high water level is produced by long-term changes in rainfall or by hurricane events.

AT HIGH STILL WATER LEVELS OVERTOPPING WOULD PROBABLY OCCUR IN MANY PLACES

With regard to storm surge simulation analysis, the report concludes that at *normal* still water levels in the lake, when wave run-up[2] is superimposed on the storm surge, low portions of the dyke would be overtopped in category 3 or 4 storms like Katrina and Wilma. However, at *high* still water levels overtopping would probably occur in many places along the dyke.

IHRC Recommendations

As average lake still water levels are approximately 2 feet higher during the hurricane season due to increased rainfall, the IHRC recommend that the higher lake level be lowered to avoid overtopping from strong hurricanes.

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[1] A “numerical simulation model” uses equations applying numerical approximations where exact solutions are not known.

[2] Wave run up: the maximum vertical extent of wave uprush on a beach or structure above the still water level.

The IHRC report also recommends that rapid changes in water pressure on the dyke due to storm surges and internal erosion need to be monitored and investigated. They suggest that a probability model be established for dyke failure due to storm surge and wave impacts.

Thirdly, the report recommends that wave and storm surge data be collected during future hurricanes and that a numerical model which could predict the combined effect of storm surge and waves be implemented.

Finally, they recommend that Light Detection and Ranging (LIDAR) surveys should be conducted to complete digital elevation data for the dyke.

LATEST POSITION

Governor's recommendations

Prior to leaving office, then Florida Governor, Jeb Bush made 9 recommendations to the U.S. Army Corps of Engineers based on the findings of the research:

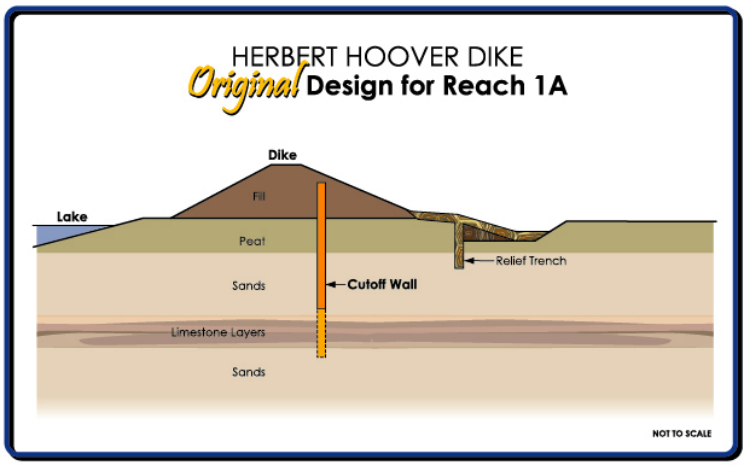
- Adopt a regulation schedule to keep Lake Okeechobee at lower levels through the hurricane season.
- Remove power poles from the toe of the dyke.
- Begin daily inspections of the dyke to ensure potential problems are identified early.
- Provide materials, equipment and personnel to make emergency repairs when vulnerabilities are identified.
- Accelerate repairs and rehabilitation currently underway.
- Re-evaluate the design of the repairs to ensure they provide adequate protection.
- Develop engineering solutions to strengthen the dyke against wave action, storm surges and seepage related erosion.
- Request congressional authorization to improve Herbert Hoover Dike to dam standards.
- Provide the best available data and evacuation support tools for hurricane threats to the State Division of Emergency Management.

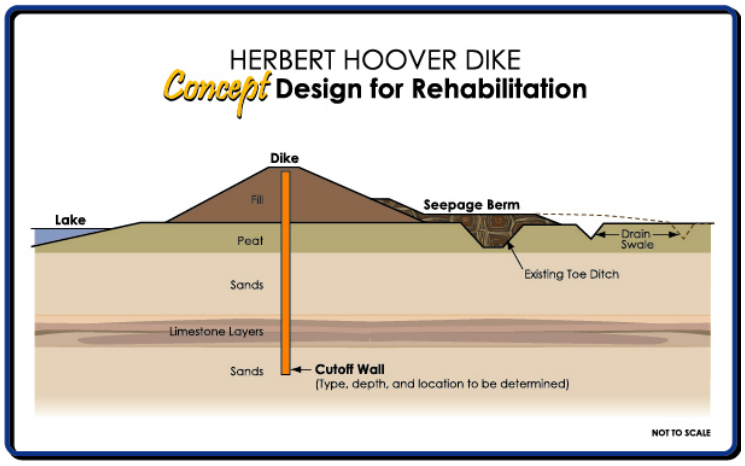
Source: The Jacksonville District, U.S. Army Corps of Engineers (www.saj.usace.army.mil)

New Design of Repairs to Herbert Hoover Dike

The response from the US Army Corps to all of the Governor's proposals has been conciliatory. In response to the recommendation regarding a re-evaluation of the design of the repairs a new design was released on 5 October 2006.

As part of the new design, a berm (a shelf or raised barrier) will be built to decrease erosion. Also, the cutoff wall will be deeper and will be built in the middle of the dyke.



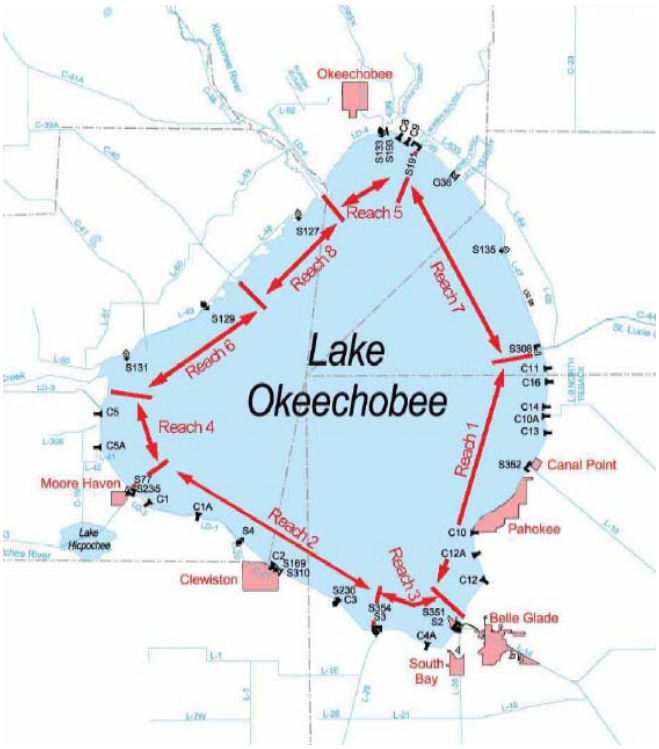


Source: The Jacksonville District, U.S. Army Corps of Engineers (www.saj.usace.army.mil)

The work began at the end of January 2007 with the priority being placed on a 50 mile section around the southern part of the lake. The lake is separated into 8 reaches; the work is to begin on Reaches 1-3 as it is believed that this 50 mile section is the most susceptible to seeping and is in most need of repair. (Reach 7 is also classified as a priority area).

Encouragingly, this also looks to make practical sense from an exposure point of view.

The map below shows the reaches of Lake Okeechobee as well as the location of each of the towns and cities which lie in close proximity to the lake:



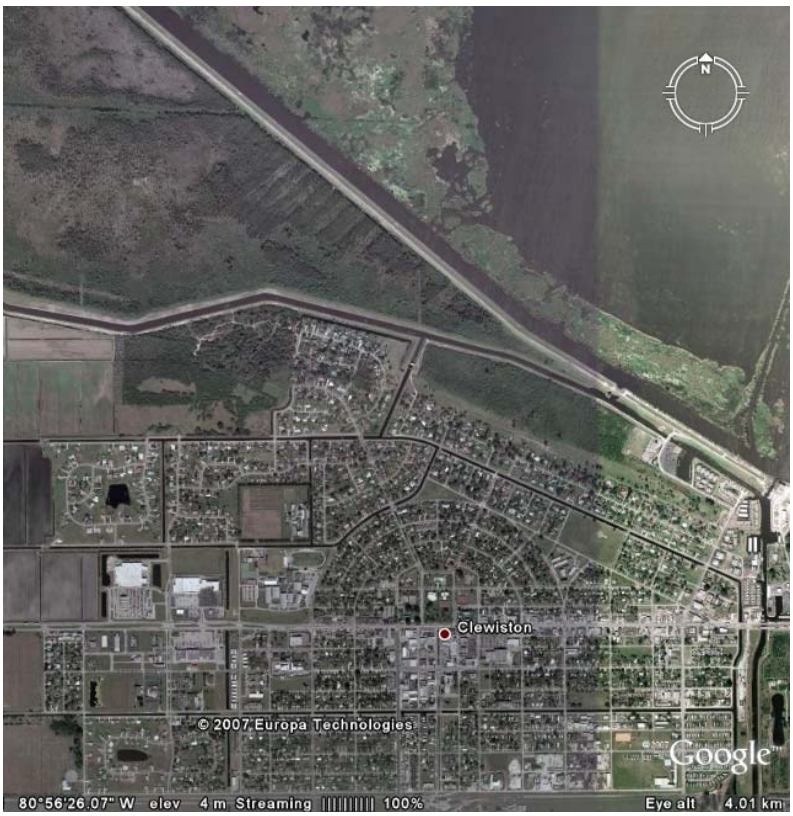
Source: Report of Expert Review Panel

Lakeside Exposures

The population of the cities which lie on the borders of Reaches 1-3 are considerable. Belle Glade and South Bay which on the south-east of the lake are shown on the Google Earth map below. These two cities have a combined population of approximately 20,000 people.

The Google Earth map below of the city of Pahokee illustrates just how close to the lake the city is. Pahokee has a population of approximately 7,000.

Another city which lies on the borders of Reaches 1-3 is Clewiston (to the South-west of the lake) which also has a population of 7,000.



THERE COULD BE FAR-REACHING EFFECTS FOR SOUTHERN FLORIDA SHOULD THE DIKE FAIL

As well as the total of 40,000 residents whose houses and lives would obviously be in serious danger, there could be far-reaching effects for the whole of southern Florida should the Herbert Hoover Dike fail. According to the Expert Review Panel Report, a vast area of to the south and east of the lake would be submerged.

To the immediate south-east of Lake Okeechobee is Palm Beach County, the third most populous county in Florida with 1.3m residents. Palm Beach County is adjacent to Broward County and immediately to the south is Miami-Dade County. These three counties between them have a combined population in excess of 5 million.

The report also comments that water supplies would be under threat and that the Everglades could be damaged, *"perhaps irreversibly".* The report continues:

"*All in all, recovery could take years, with indirect losses far exceeding direct damages and likely running to the tens of billions of dollars."*

OTHER FACTORS

The US Army Corps of Engineers have stated that they are to revise their plans which will mean that the water levels in the lake will be maintained at a lower level during the hurricane season.

However, the work to completely repair the dyke will not be completed for several years incorporating several hurricane seasons.

Therefore, despite the improvements that are to be implemented, there is still a danger that the dyke may not be able to prevent a flood event, at least in the immediate future.

According to the US Army Corps of Engineers, the work on the three reaches is expected to last for five years and is likely to cost approximately USD 10m per mile for the new design, equal to USD 500m. Until this repair work is completed, the risk levels associated with the Herbert Hoover Dike are elevated.

HURRICANE ACTIVITY WILL BE ABOVE THE LONG-TERM AVERAGE FOR THE NEXT 20 YEARS

Climate change

Despite the unexpectedly quiet 2006 Atlantic hurricane season most experts maintain that intense hurricane activity will be above the long-term average for at least the next 20 years based on natural cycles in sea surface temperatures alone.

Climate change can only exacerbate this, and insurers must plan for a higher frequency of extreme events, over a longer storm season and over a wider geographical area.

Climate change has already had an impact on sea levels which are 10 to 20 centimetres higher than at begin of 20th century and rises in sea levels are expected to accelerate in the 21st century. Therefore, storm surges are likely to be higher offshore. If this is coupled with a flooding of inland lakes or rivers, this will prevent the run-off of flood water and inevitably lead to increased damage.

Insurers must also take advantage of research papers, such as the SFWMD report and scientific advances to factor forecasts when pricing catastrophe exposed risks and not rely solely on long-term trends.

Limitations of Catastrophe Models

Recent events have shown the problems of over-reliance on vendor catastrophe models. Initial estimates of loss from these models for Hurricane Katrina were significantly underestimated.

The models focus on losses from wind damage and in the case of Hurricane Katrina, a large proportion of the losses came from flooding and storm surge. Although insurance coverage is normally limited to hurricane damage, flood losses may end up being insured or contested. It is extremely difficult to separate the cause of loss, i.e. flood from wind damage, in an event as complex as Hurricane Katrina.

Assumptions within the catastrophe models, for example, regarding building vulnerability and demand surge combined with poor insurer input data quality and underestimation of replacement costs also contributed to these erroneous estimates.

THE MODELS, IN GENERAL, DO NOT MODEL LEVEE FAILURE AT LAKE OKEECHOBEE

The vendor catastrophe model suppliers have never claimed to fully model all aspects of the risk, nonetheless they have done a lot of work to upgrade and improve their models since the events of 2005.

However, the lessons of 2005 in respect of how to interpret model results must be learnt. While the models are useful tools, they should not be used in isolation. The US hurricane models, in general, *do not* model levee failure at Lake Okeechobee. Insurers must be aware of all possible sources of potential loss when pricing risks, managing portfolios of correlated risks and establishing capital requirements to support their business plans.

CONCLUSIONS

- It may, at first glance seem rather odd that the Lloyd's Emerging Risks team concentrates its first report on a naturally occurring lake which was formed around 6,000 years ago.
- However, this is the US mainland's most vulnerable area to hurricanes after New Orleans, and the continually rapid growth in population of Florida combined with the revelation that there are serious issues with the Herbert Hoover Dike leads us to believe that the risk from a flooding event involving Lake Okeechobee has yet to be fully understood and evaluated by the insurance industry.
- The dyke protects approximately 40,000 people who live within its immediate vicinity. These people and their properties would be in serious danger should the dyke fail. However a key report considers that failure of the Herbert Hoover Dike would be a catastrophe for the whole of Southern Florida.
- Due to natural cycles and climate change, insurers must plan for a higher frequency of extreme events over both the short and long term. Insurers should take advantage of scientific advances and updated research to factor forecasts for the hurricane season ahead into their planning, instead of relying on long-term trends. Though model output is only reliable when the input data is reliable and of sufficient quality.
- Catastrophe models are not a panacea. In the aftermath of the 2005 hurricanes, it became clear that some model users did not have a sufficiently good understanding of the key assumptions behind the models. Insurers should assess all relevant criteria when assessing correlating risks and exposures. Insurers should consider how non-modelled perils and territories might contribute to the overall assessment of loss potential.
- Florida bill HB 1A was signed into law on 25 January 2007. While the immediate impact on the Lloyd's market is unclear, HB 1A contains provisions relating to many different aspects of the Florida insurance industry and we continue to monitor how it will be interpreted by subsequent regulations.

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