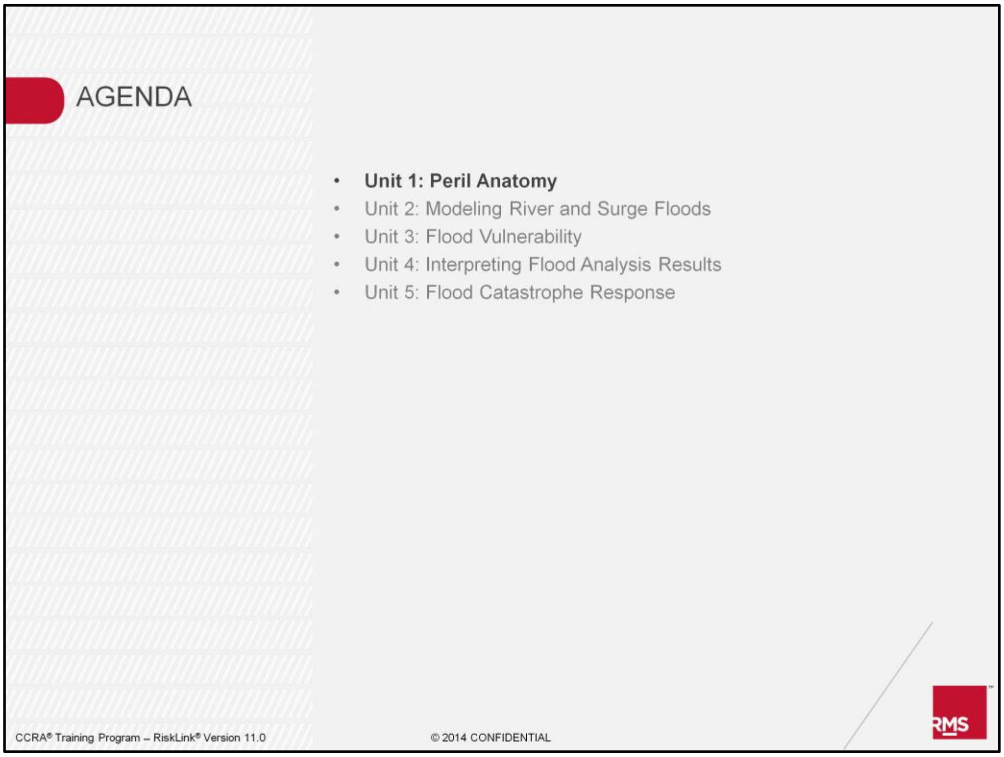
FLOOD MODELING

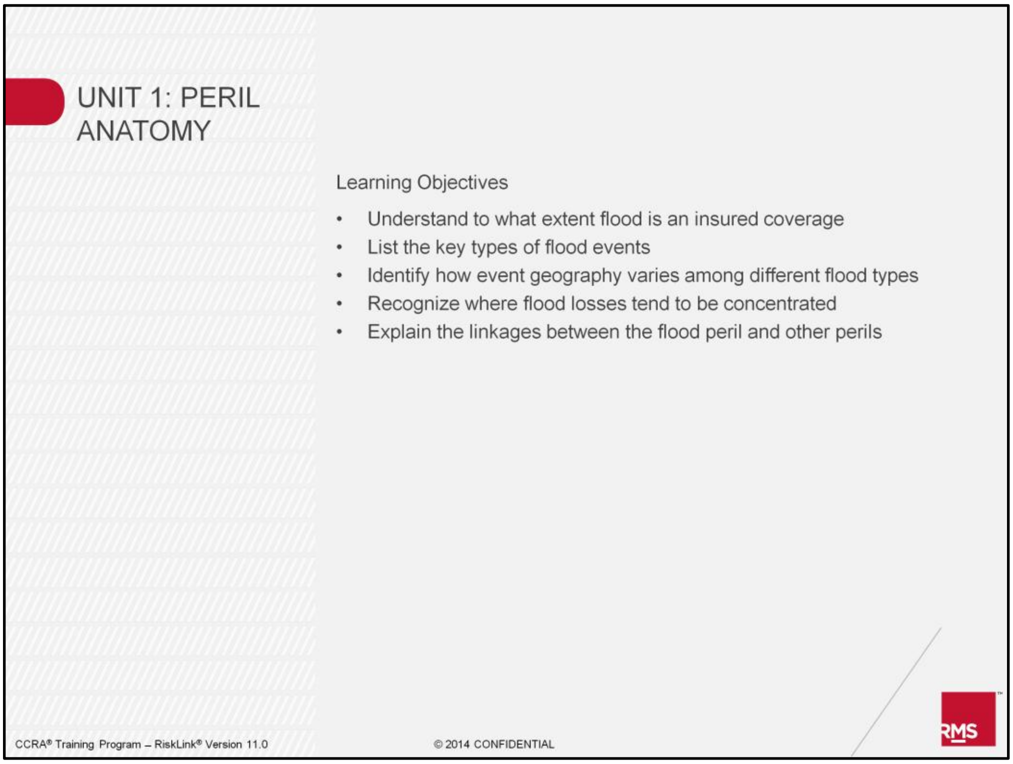
UNIT 1

RMS® CCRA® Training Program

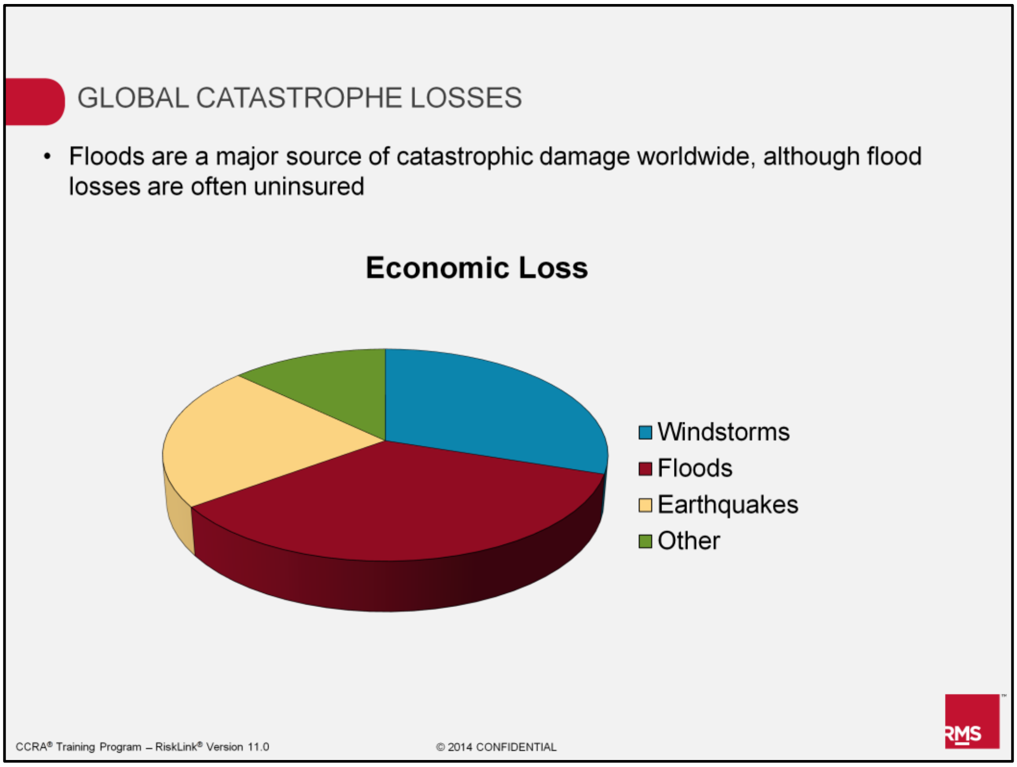
Certified Catastrophe Risk Analyst



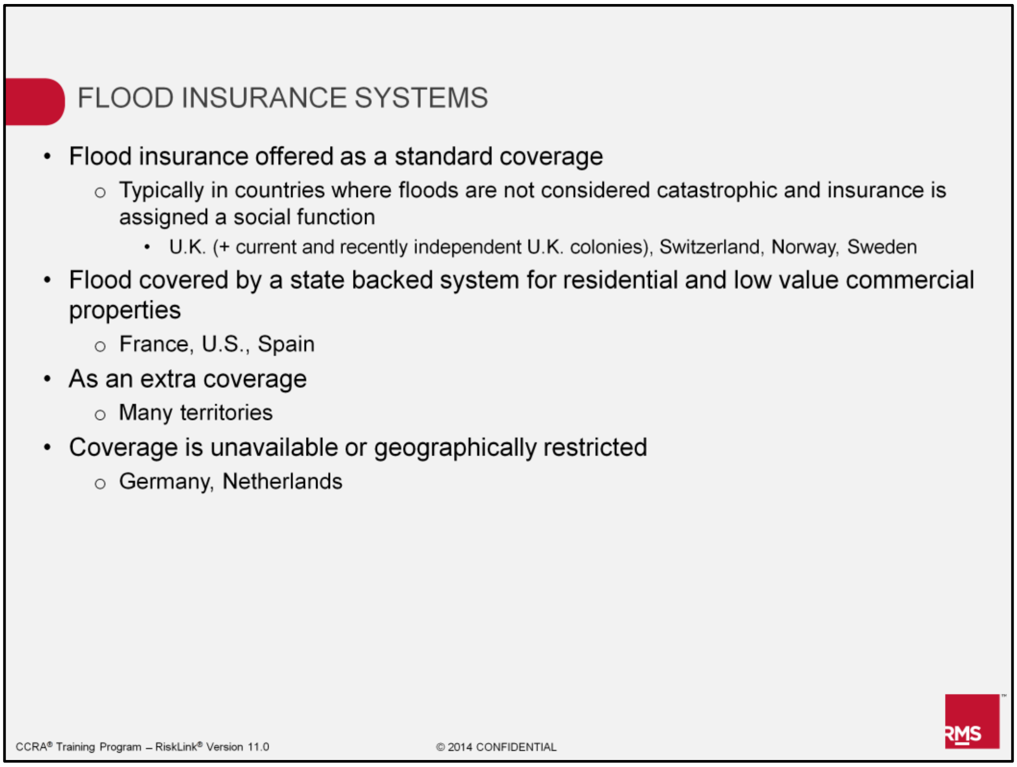
This unit discusses the vulnerability module of the Europe windstorm model.



At the end of this unit you should have a good understanding of each of the five learning objectives listed on this slide.



On a global scale, floods are a major source of catastrophe loss and catastrophic damage. They constitute almost one-third of the total economic losses associated with natural catastrophes. But at the same time, many of the flood losses that do occur are often uninsured. In fact, the proportion of flood damage that is insured is much lower than windstorm. So while flood may constitute 30-40% of global catastrophic loss, it may only constitute around 10% of global insurance loss.



Worldwide, you will find that generally flood is not a standard insurance coverage, and flood insurance varies greatly from one country to another. There are two categories of countries where there is general flood insurance; one is dominated by private insurance, and the other is dominated by government sponsored insurance. In the U.K. and its current and recently independent colonies, the insurance policies tend to include flood as a standard coverage. That is because over the last few decades there have not been any events so catastrophic as to discourage the insurance industry from bearing the risk.

There are also some other countries, for example, Switzerland, Norway, Sweden, and Iceland, where insurance is seen to provide a social function, which is probably less true in the U.K., and therefore there is considerable public and government support to ensure that flood coverage is generally available. At the same time, these countries also tend to be mountainous and there are not such large concentrations of flood risk as there are in continental regions where there are very long river systems. Because there is a lack of risk concentration in these countries, flood coverage is generally available in the private market. On the contrary, countries which have problems with aggregation of flood risk generally will not have coverage available in the private market.

In some other territories, in both Europe and the U.S., flood risk is covered by a state-backed insurance system rather than a private insurance system. This is typically for residential and low-value commercial properties, while higher-value properties and commercial and industrial may be covered by the private market as an extra coverage, at an extra premium. Furthermore, the coverage may be declined if the underwriter thinks that the risk is too high or they have too much aggregate flood risk in that portfolio. In most states in Germany flood coverage is fairly limited and it may be unavailable to individuals who are at highest risk.

There are also a couple of territories where flood insurance is generally unavailable, in particular the Netherlands, as the result of the catastrophic storm surge floods of 1953. The insurance industry decided that it was really the government's responsibility to provide flood protection and that by offering flood insurance they would be discouraging the government from taking due action to reduce the risk.

DIFFERENT CLASSES OF FLOOD

- River Flood
- Flash Flood
- Storm Surge Flood
- Tsunami Flood

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The different classes of flood events will now be explored. Four categories of floods are considered.

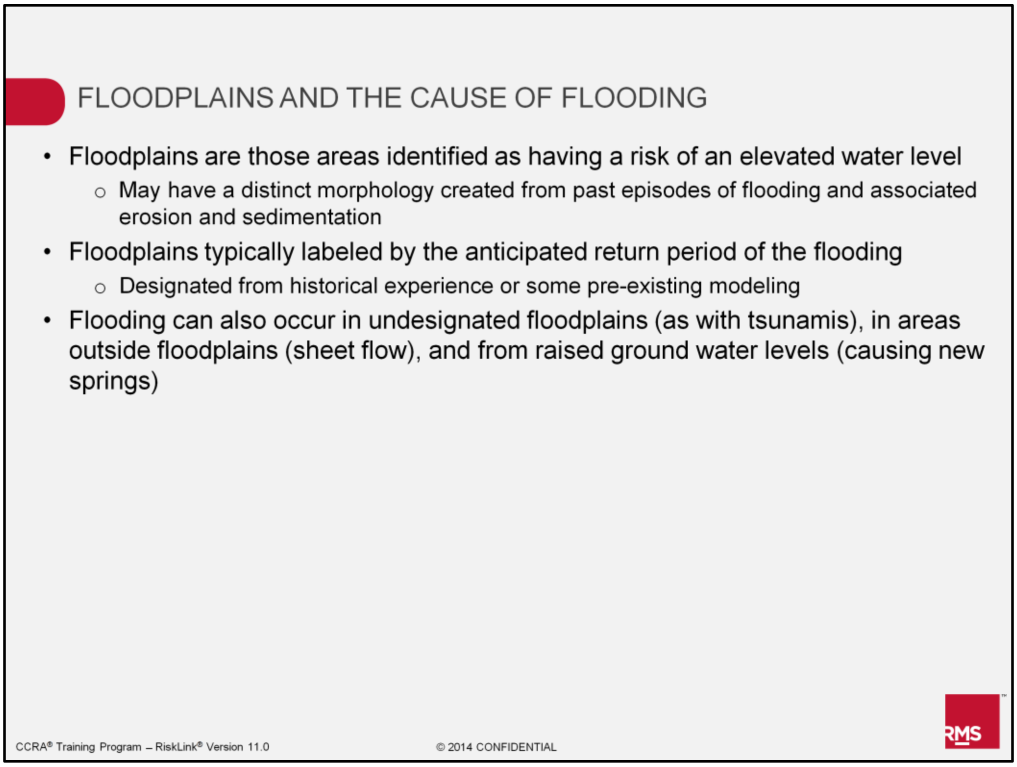
The first of these are river floods where the damage is predominantly caused by water flowing out of the river because the volume of flow exceeds the capacity of the river channel itself.

A flash flood, the second category, is caused by excess precipitation typically over a short time period such as an hour or few hours. Flash floods are a combination of small streams showing dramatic increases in flow and water running directly off the land.

The third category is storm surge flood, which is associated with the impact of an extreme windstorm pushing and driving the water so that it piles up onto the land, as well as the low pressure system which may be at the center of such an extreme windstorm circulation causing some rise in the level of the sea.

The last category is a tsunami flood. A tsunami flood is associated with a sudden displacement of the sea floor causing a wave to flow onto the neighboring land areas. Sometimes the wave flows all the way across an ocean and then onto the neighboring low-lying land areas.

These categories have some features in common yet some distinct characteristics.



It is worth explaining a term which we are going to use often in this course - the floodplain. The floodplain means the area of low-lying land surrounding a river or next to a coastline which has the potential to become flooded. That definition may seem very simple, but one should also be thinking about the probability associated with that flooding because as the extent of the floodplain increases, the lower the annual probability of flooding. So it is worth always qualifying, if possible, what is meant by a floodplain. For example, some government agencies may designate an area as floodplain with a return period of 100 years, or one percent probability of being flooded in a given year.

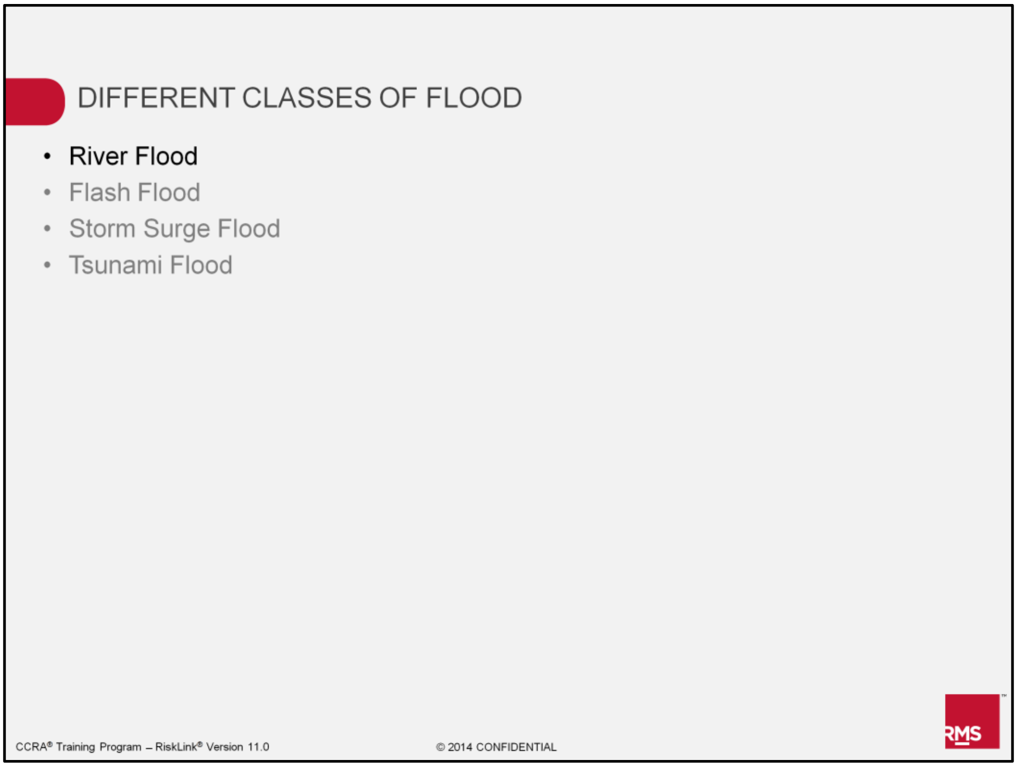
Typically the river channel contains the flow under most conditions but occasionally there are extreme flow events when the water spreads out into the surrounding lowland. Floodplains often have a very characteristic morphology which is a function of having been affected by past episodes of flooding that have caused erosion and subsequent sedimentation. That is true both of river floodplains and coastal floodplains.

It is important to label the return period of the flooding in a floodplain whenever possible. This in itself is often not very straightforward because it requires some analysis in terms of historical experience or hydraulic modeling as to what exactly is meant by the "100-year floodplain" or the "500-year floodplain."

In addition, those "floodplains" are often classified by a government agency of hydrology which typically has the challenge of deciding how small the streams are along which it should be considering the definition of floodplains. Once an area is defined as a floodplain, then it may have specific implications, such as when planning for new developments. In many countries the term floodplain may be restricted only to the larger rivers. Below a specified stream size, floodplains may not be defined, even though the stream may still have a low-lying area surrounding it which has the potential to become flooded in an extreme rainfall event – exactly as it would for a river.

We also find that some flooding occurs completely outside of those areas which will be filled by water if the stream or river overflows. We can call this kind of flooding sheet flow. These are areas where run-off simply passes downhill, running over land, and causes flooding. We may also find flooding as a result of a rise in the water table, or the water in the ground, to the point where new springs form. This in turn can cause flooding.

So there are other sources of flooding that occur outside floodplains, and the term floodplain needs to be qualified by whether it is defined by an agency and, therefore, likely omits the smaller streams, or by another organization.



The first class of flooding that will be discussed is river floods.

RIVER FLOOD TYPES

- Rainfall (precipitation driven)
  - The larger the catchment, the longer the duration of the precipitation extreme required to trigger a flood
- Snow-melt flood (temperature and rainfall driven as rainfall enhances the thaw)
- Damburst flood (may be precipitation driven)
- Volcano flood “johkulkaup” (associated with eruption beneath a glacier)
- In mountainous areas, precipitation floods likely to be associated with landslides and debris flows

Prague 2002

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In contemplating the different classes of river floods, the predominant driver for river flooding is excess rainfall. The larger the catchment area, the larger the river is itself in terms of width and depth. Therefore, large river catchments can accommodate greater volumes of rainfall that then flow into the river channel. The larger the catchment area, the longer the duration of extreme rainfall needed to trigger a flood.

One way of thinking about river systems is that they are “tuned” to a particular duration of rainfall. For a small stream, flooding will be a response to an extreme rainfall event lasting over a few hours. But for very long, large river system, such as the Mississippi River, there are typically high levels of rainfall that may have lasted several weeks and covered a large part of the tens of thousands of square kilometers of the catchment. We have to recognize that when we think about rainfall extremes in their link to flooding, the duration of the rainfall extreme will be different according to the size and extent of the river catchment system.

Rainfall is not the only driver of extreme floods. We can also have floods as a result of melting snow, typically also accompanied by rainfall because rainfall on thick snow enhances the speed at which the snow melts. We can also have floods as a result of dam bursts. These dams may be either man-made or natural dams. An example of a natural dam is when a landslide temporarily blocks a river and then breaks to release a large volume of water. Another natural dam example is a dam formed by ice carried down river and getting jammed into a large pile. These ice dams may eventually burst and cause a river further downstream to flood.

We can also find floods as a result of a volcanic eruption underneath a glacier. These floods are known as "johkulkaups," which is an Icelandic word. These are very characteristic of the ice sheet under southern Iceland, which has volcanoes underneath it. A huge reservoir of water builds up in the ice sheet until it finally bursts out.

Finally, in mountainous areas, floods associated with high precipitation are often accompanied by landslides and debris flows which may themselves cause temporary blockages in rivers. These may burst and cause larger pulses of water to flow downstream.

CASE EXAMPLES OF RIVER FLOOD

- Largest river floods affect a wide region
  - In watershed (elevated/mountainous) region, often affects different river systems
  - For large continental river network, likely to affect only parts of the overall catchment
- The cooler the season and the higher the latitude, the more that flooding is likely to be a consequence of multiple weather systems.
  - Multiple weather systems likely to affect a broad region in a complex way – i.e. patchy impact of flooding
  - Single weather systems more likely to have a coherent precipitation footprint

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The area over which the extreme rain falls will often span more than one river catchment. If it is over a mountainous region, then flooding may occur on rivers on different sides of the mountain which may flow towards separate seas – as in the rivers on either side of the Alps. On the largest continental river networks, even the most extreme, long-lasting precipitation events typically only affect parts of the overall catchment. So for a river the size of the Mississippi, for example, it would be almost unprecedented to have extreme rainfall across the whole catchment of the river. Typically, there may be extreme rainfall in one-quarter or one-third of the overall catchment.

Further to the north and the cooler the season of the year, the more likely that a flooding event is a consequence of multiple weather systems. As it gets cooler in higher latitudes, the moisture-carrying capacity of the atmosphere decreases, and therefore, it is not possible for a single weather system to create an extreme flood. Rather, it may be a consequence of a whole series of storm frontal systems moving in, each one bringing rain, and each one adding to the rain which was left by the previous one.

As a result, at high latitudes it is quite common that a flood event is represented by a footprint of “patches” of flooded areas. This is in contrast to lower latitudes where flooding is more often caused by a single, concentrated meteorological phenomenon, and will therefore have a more coherent precipitation footprint.

CASE STUDIES FOR RIVER FLOOD

- U.K. March 1947, rain after freezing and snow
- France January 1995, series of extra-tropical cyclone (ETC) storms
- U.S. summer 1993, Mississippi regional flood
- Central Europe July/August 2002: Regional flood affecting two separate continental catchments
- Dam/defense failures: Three examples from Mississippi, Rhine, Teton Dam

Aerial view of the Missouri River flooding on July 30, 1993, in the vicinity of Cedar City and Jefferson City Memorial Airport immediately north of Jefferson City, Missouri, looking south (photography from the Missouri Highway and Transportation Department).

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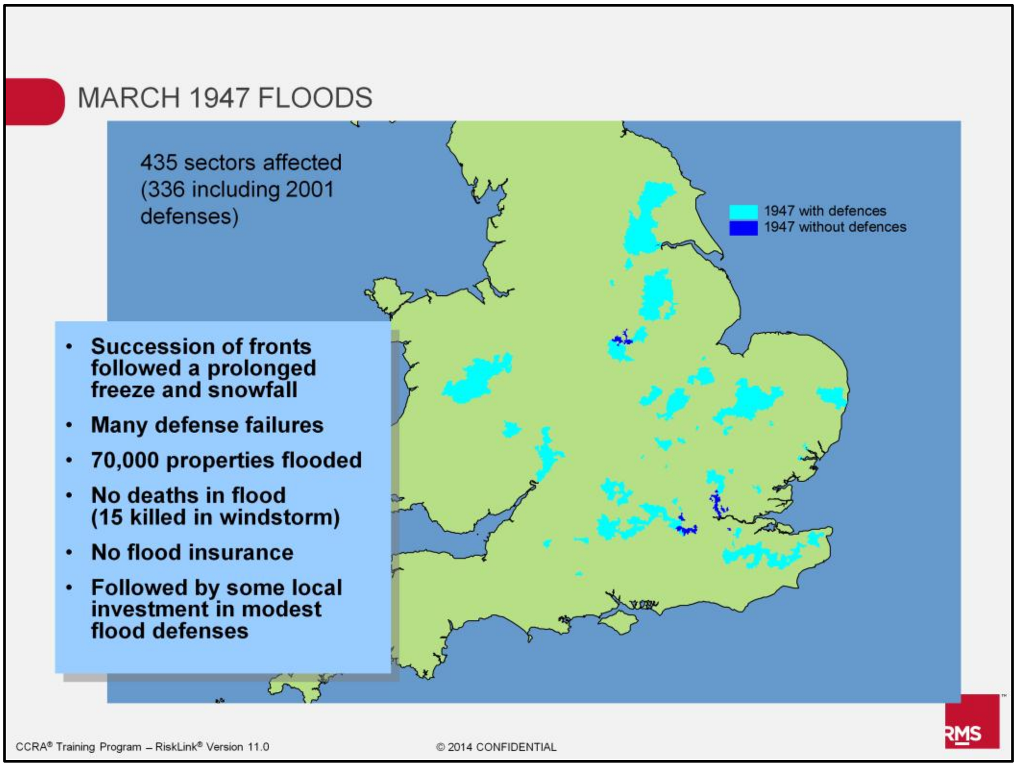
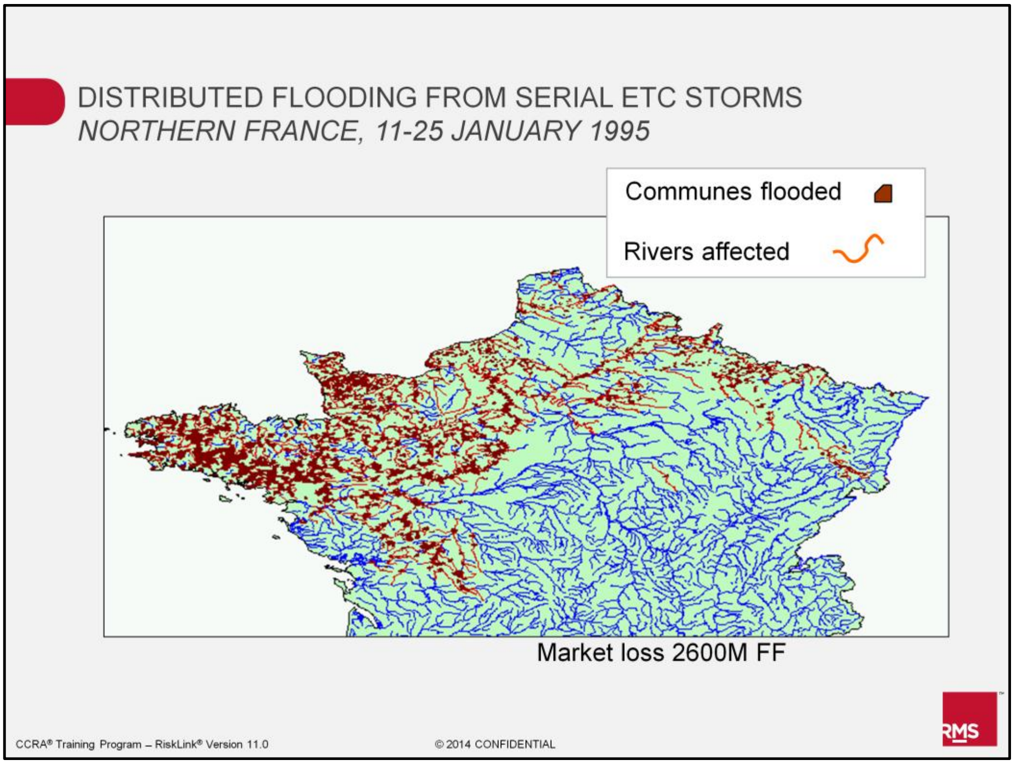
This slide lists several case studies for river flood, which we will look at in more detail in the following slides.



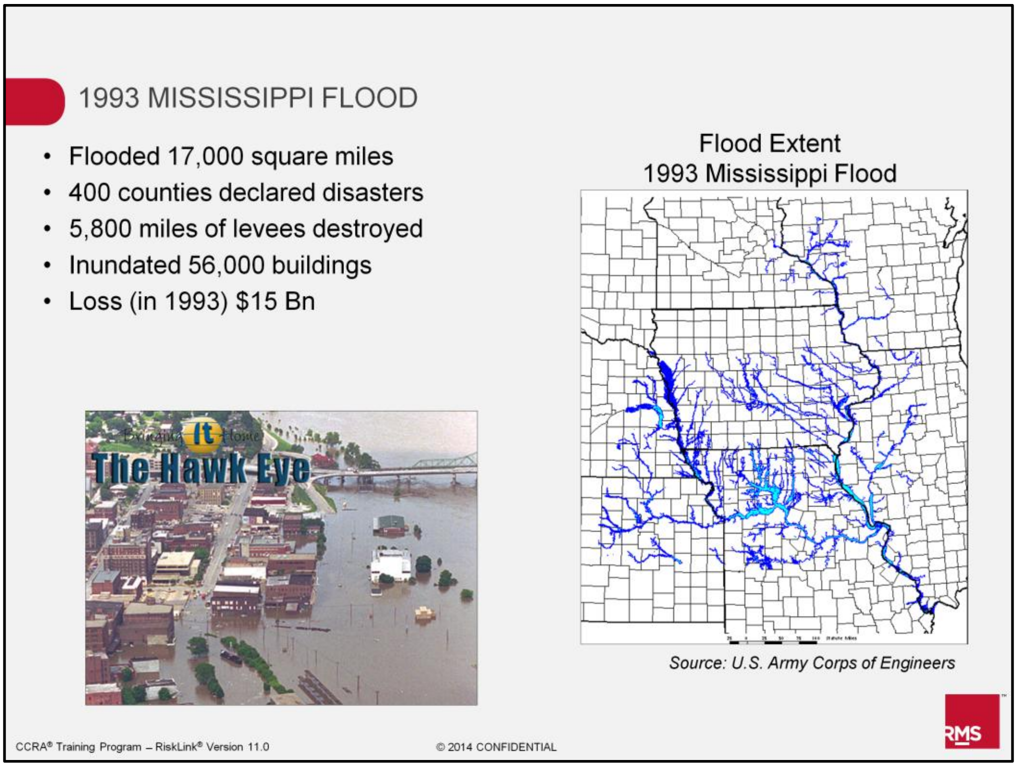
The largest and most extensive U.K. flooding event to occur in the past 200 years occurred in March 1947. This event was caused by a succession of fronts moving in off the Atlantic which followed a prolonged period of extreme cold and snow. There was a very rapid thaw as a result of significant rain.

Because there was a succession of fronts, the distribution of the flooding was very scattered across a board region of both England and Wales. This episode of flooding ultimately inundated approximately 70,000 properties. There was also an accompanying windstorm as part of the same sequence of events. There was no flood insurance at the time, and as a result, no records were kept of the overall economic damage. We know if this event occurred today with the same areas flooded, it would probably flood at least twice as many properties as were flooded in 1947.

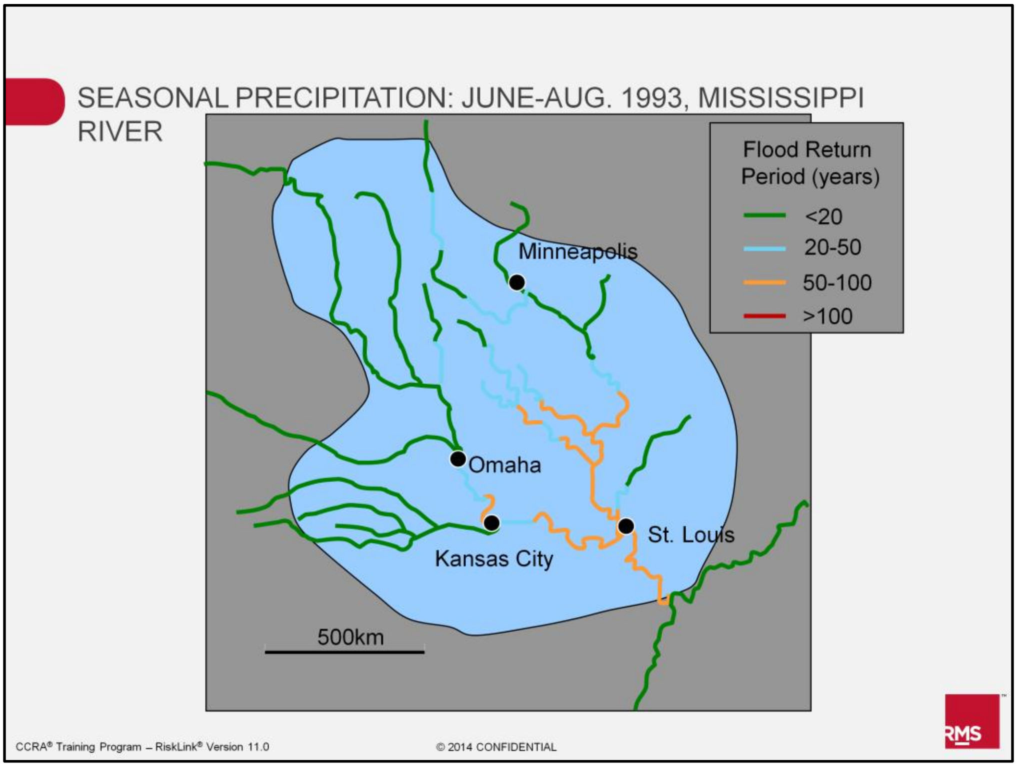


This is another example of a distributed flooding event, which is a consequence of a series of extra-tropical cyclone (ETC) storms, coming in off the Atlantic. This is the flooding that occurred in northern France in January 1995.

The brown dots on this map represent individual communes - small villages and towns in France that were flooded in this event. The river systems that experienced flooding in this event are in orange. In this two week event, the flooding was distributed across a broad area. It was very patchy in nature. In some areas there was concentrated flooding. In other areas there were only a few rivers impacted with the surrounding region not badly affected at all.



The 1993 Mississippi flood inundated about 17,000 square miles of the upper Mississippi River region and destroyed almost 6,000 miles of the embankments that were built to protect the surrounding area. Fifty-six thousands buildings were flooded in the event. Although the loss is estimated to have reached about $15 billion (in 1993), the large majority of that was agricultural loss. The insured property losses were under $1 billion.



This Mississippi event lasted from early to mid summer of 1993 when there was a period of prolonged heavy rainfall across this region. Many bands of thunderstorms came across this area as the jet-stream remained in the same location for many weeks.

This map shows the flood return period along the different tributary rivers of the upper Mississippi. The pale blue is the area in which the higher rainfall was experienced. That area is about 1,000 kilometers across and perhaps 1,500 kilometers from north to south. The rivers are colored according to the return period of flooding.

In the headwaters, the flood return periods are generally less than 20 years. Note that the flood return periods tend to increase downstream. This is because a wider region is being impacted by the extreme precipitation, as the headwaters converge. Remember, there is an inverse relationship between the size of a floodplain and the flood return period.

Ultimately, the flood return periods increase to be between 50 and 100 years as the different tributary branches converge in the vicinity of St. Louis, Missouri. Where the Mississippi River joins the Ohio River south of St. Louis, extreme flooding did not occur downstream into the lower Mississippi because the Ohio River was not experiencing extreme flows at the same time.

2002 CENTRAL EUROPE FLOODS

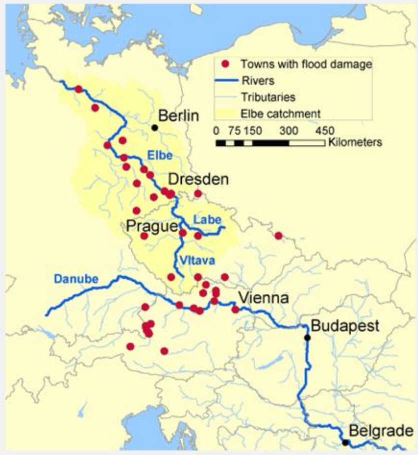
- Economic damage

Germany	€9.2 bn
Austria	€2.9 bn
Czech Republic	€2.3 bn
Total	€14.4 bn

- Insured losses

Germany	€1.8 bn (20%)
Austria	€0.5 bn (17%)
Czech Republic	€1.1 bn (48%)
Total	€4.4 bn (31%)

Source: Converium



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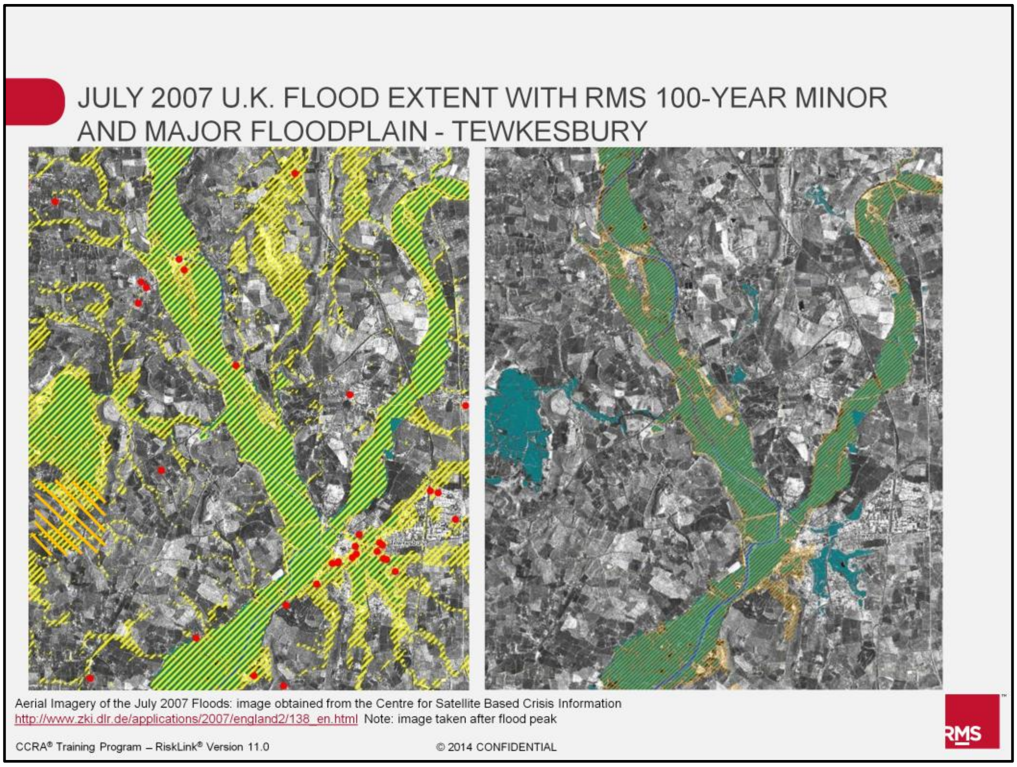
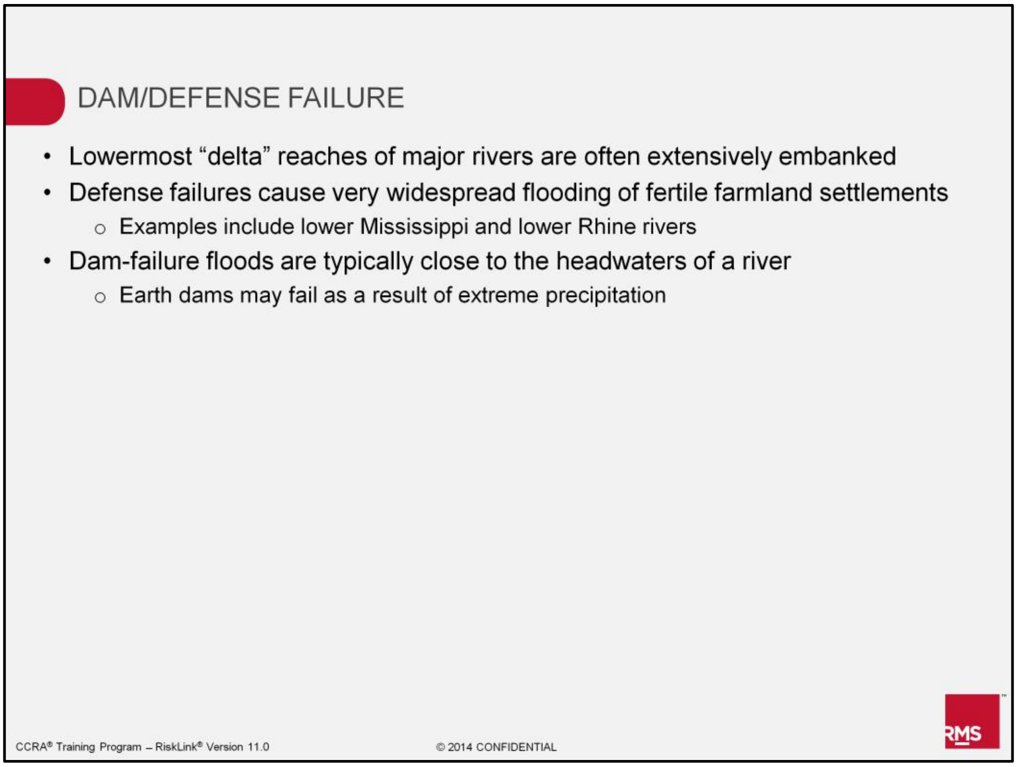
A major central Europe flood event occurred in 2002 and affected rivers going north and towards the southeast across Europe. The main extreme precipitation event was concentrated in the Czech Republic and across the border into Austria and southeast Germany. The principal rivers impacted were the Danube, flowing towards the southeast, and the tributaries of the River Elba flowing toward Prague and Dresden.

Here we see a precipitation event that fell in the headwaters of two major river systems which might otherwise have been considered independent. The economic damage of these floods was estimated to have been in excess of €14 billion. Only about 30% of this loss was insured, partly because in Germany, flood insurance is largely concentrated in the former East Germany. Many of the policies offered in the past in what was East Germany which covered floods are still in force today. In Austria, flood coverage is fairly limited, as in much of the west of Germany. In the Czech Republic, flood was more widely offered as a standard insurance coverage.



Another precipitation event which occurred in July 2007 in the U.K. is shown here. The images on this slide show the RMS 100-year major and minor floodplain for Tewkesbury in the U.K. This event was the result of a slow moving low pressure system that produced heavy rainfalls. The extreme rainfall amounts put enormous amounts of pressure on drainage systems and many locations experienced flash flooding as a direct result of rainfall runoff. Many smaller rivers and streams burst their banks within hours of the deluge, leaving many homes flooded.

The rainfall throughout the summer of 2007 had been record breaking, providing ideal antecedent conditions for flooding. According to the U.K. Met Office, over 378 mm (15.2 inches) of rain fell in England and Wales in the three months leading up to this July event. This is more than double the average rainfall for the period.

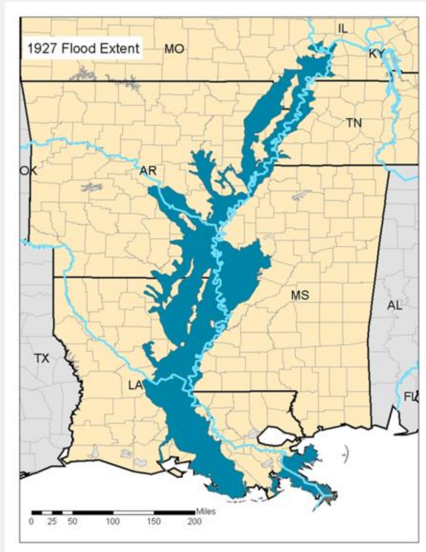


Earlier we mentioned the fact that dam and defense failures can contribute to flood loss. Embankments around rivers are more common where the floodplain broadens out in the lower reaches of major rivers and along principal rivers such as the Mississippi or the River Rhine. Because the land surrounding the river is extremely valuable for agriculture, great efforts have often been made to build high embankments to protect that land. Clearly, if these embankments should fail, then the flooding can cover a very wide area. Both the lower Mississippi and the lower Rhine have been subject to embankment failure in the past that have caused very widespread flooding.

At the other end of the river systems, in the headwaters, there may be dams that sometimes fail as a result of an extreme rainfall event. In particular, earth dams, especially older earth dams, may be overtopped and fail, causing additional flooding.

1927 MISSISSIPPI FLOOD: WHEN THE LEVEE BREAKS

- Flooded 27,000 square miles
- Drowned: 246 people
- Displaced: 700,000 people
- Inundated 137,000 buildings
- Loss (in 1927) $347 M
- Loss (2008 exposure) $33 Bn



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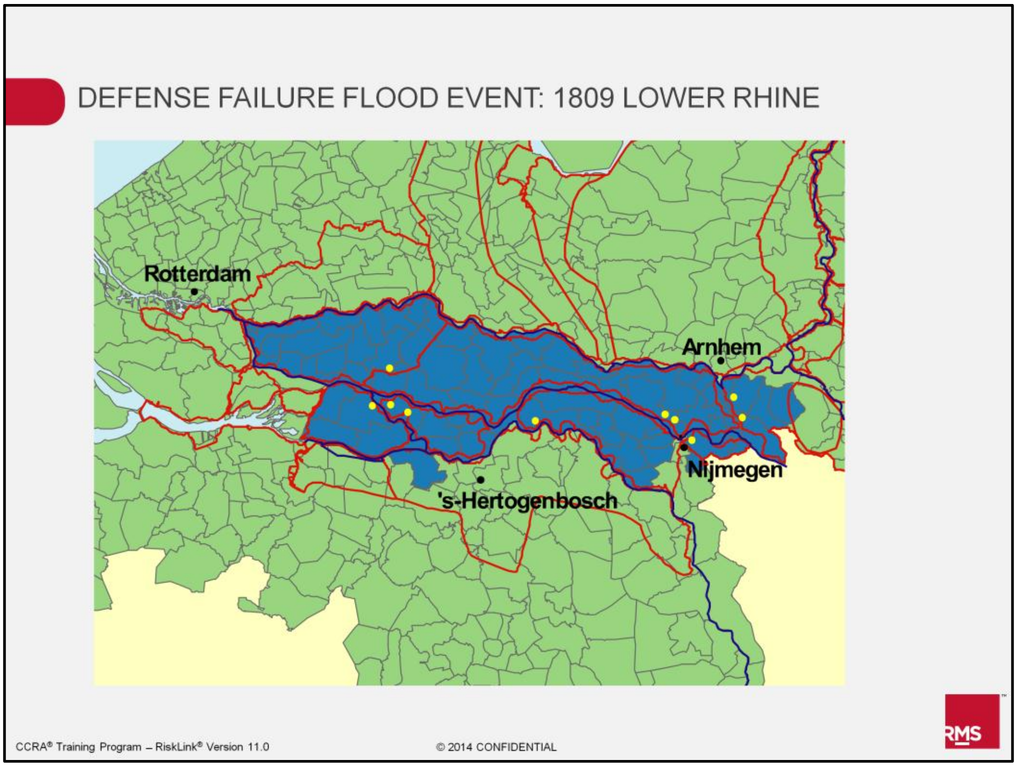
The 1927 flood on the lower Mississippi is an example of flooding caused by the bursting of embankments. Twenty-seven thousand square miles were flooded over the large areas of flatland surrounding the river. In some places the water overtopped the levees and found a completely different route for hundreds of kilometers and then re-entered the river further downstream. At the lower end of the river the flood water found a completely new path to the sea separate from the path of the Mississippi River thus protecting the city of New Orleans. In this particular event, the city fathers had the embankments dynamited further downstream in an attempt to protect the city. This was later found out to be unnecessary because the water had found this new path to the sea.

This huge event displaced 700,000 people and inundated 137,000 buildings. If footprint of this flood was placed on the exposure today, industry losses are estimated to be approximately $33 billion for this event. Since the 1927 flood, the embankments along the river have been built to a higher standard but ultimately, at some return period of flow, have the potential to fail as they did in 1927.

1976 TETON DAM FAILURE

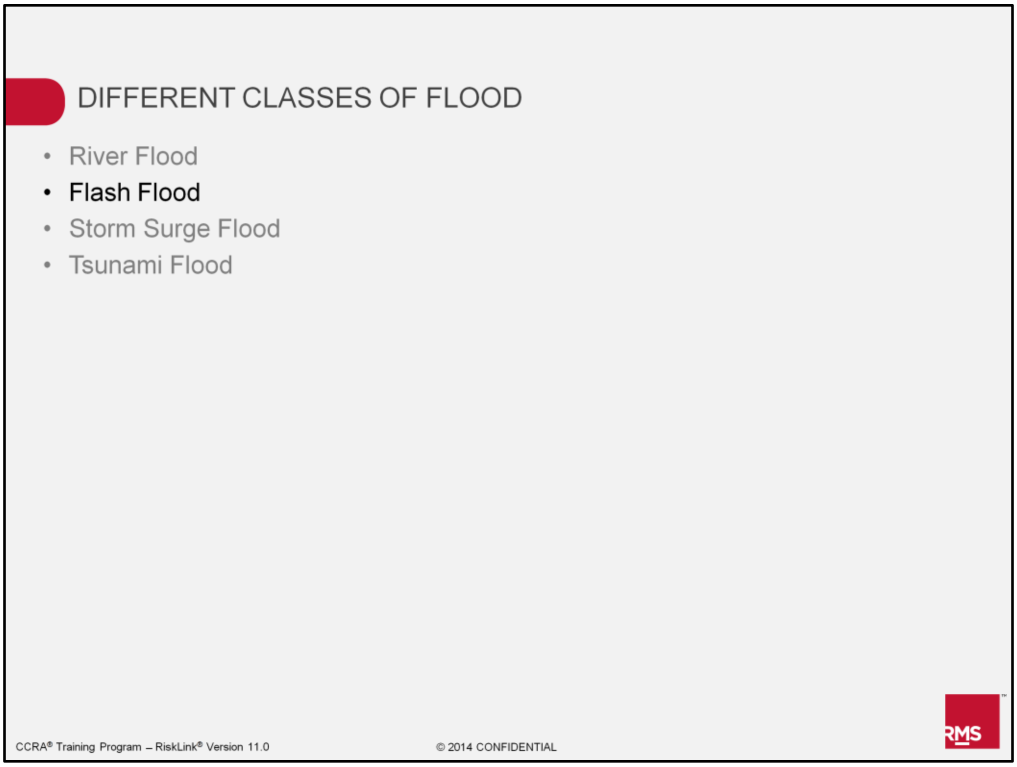
- Occurred on June 5, 1976
- Flooding in the cities of Sugar City and Reburg in Idaho.
- Killed 14 people and caused over $1 billion in property damage.
- The dam failed because the bedrock was not strong enough to support the structure.

Dam failure is another source of historical flooding. As an example, the Teton Dam, 44 miles northeast of Idaho Falls in southeastern Idaho, failed abruptly on June 5, 1976. It released nearly 300,000 acre feet of water, then flooded farmland and towns downstream with the eventual loss of 14 lives, and with a cost estimated to be nearly $1 billion. The dam failed because the bedrock was not strong enough to support the structure.

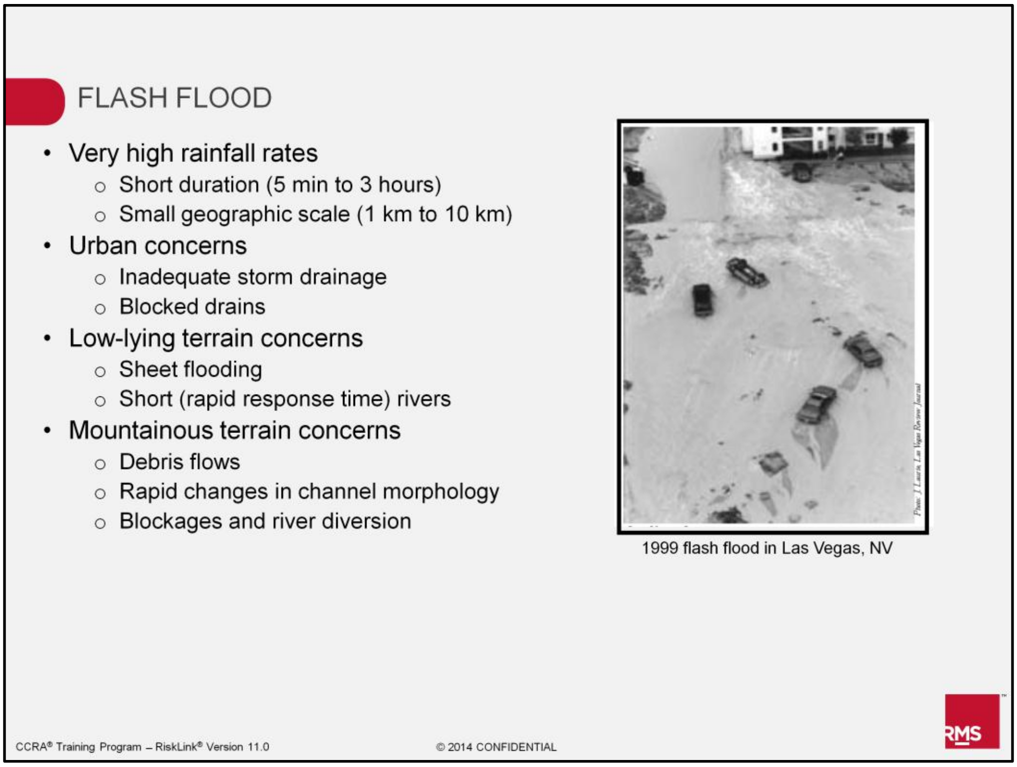


The 1809 Rhine River flood is an example of one of several northern Europe historic flood defense failures. The yellow dots shown on the map mark the points where the embankments on the river that existed at that time failed. There were a series of polders, which are low-lying areas surrounded by embankments. Even though the River Rhine burst its banks, the water was contained within these polders. These polders were tens of kilometers across and today include many major towns with large populations in them.

In 1995 there was an extreme flow on the River Rhine and a fear that an event comparable to 1809 might be repeated. In response there was a mass evacuation of a number of Dutch towns located in the floodplain.



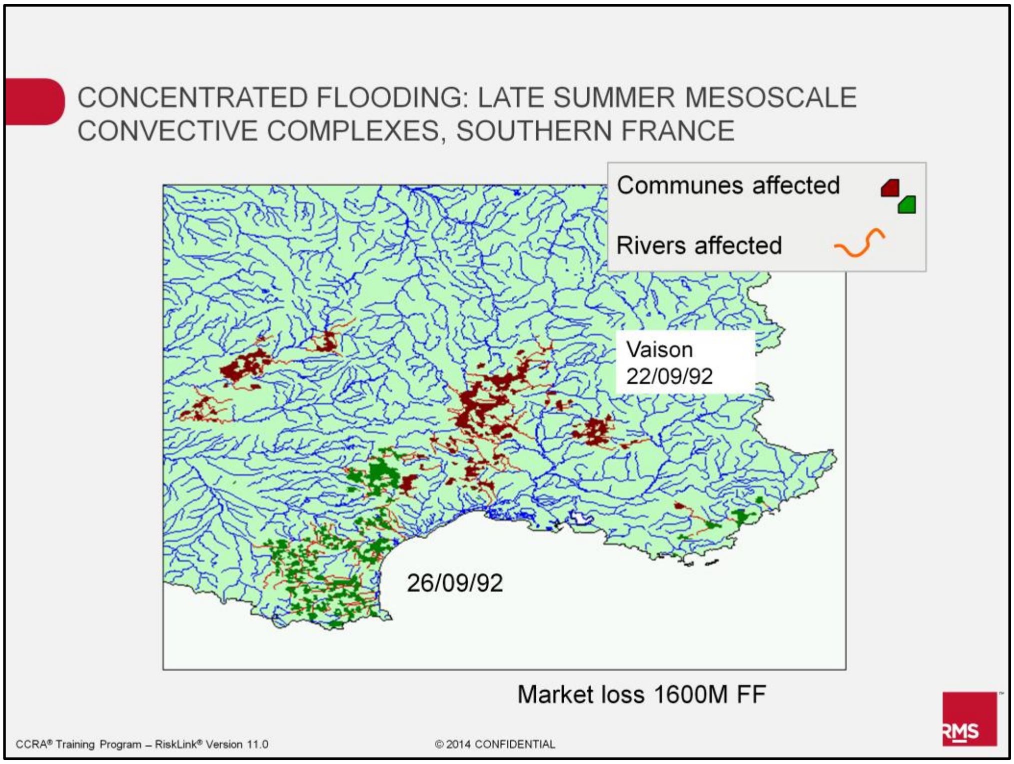
The next group of slides cover the topic of flash flooding.



Flash flooding is associated with very high rates of rainfall within small temporal (five minutes to three hours) and spatial scales (1 to 10 km). Although flash floods can cause the most spectacular damage in mountains, the biggest concern is often urban areas. If rainfall exceeds the rates to which the storm drains are designed streets become channels down which the water will flow. This rainfall rate for storm drains is typically sampled over 10 minutes or an hour. Once storm drain capacity is exceeded (or drains become blocked with debris) water flows through the streets. Drains can also get blocked with debris washed into them and that in turn can displace water causing it to flow through the streets. This is a common source of flood loss.

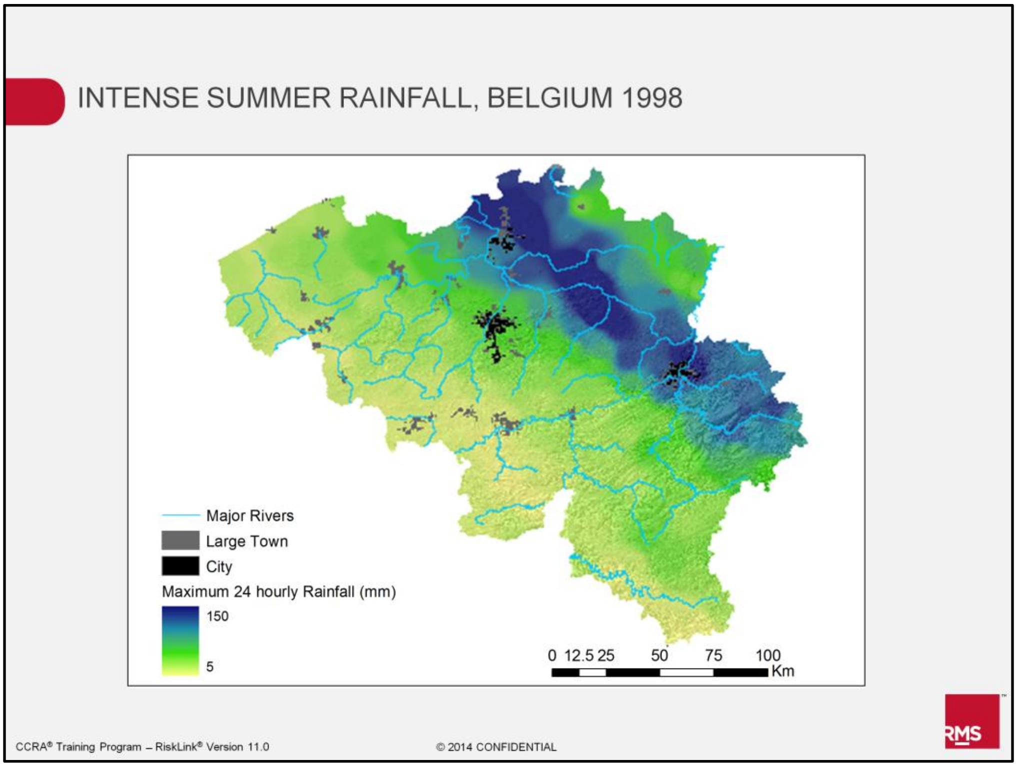
Flash flooding in low-lying or mountainous terrains has separate concerns. For low-lying terrains, sheet flooding, or water run-off over land outside of floodplains, is a particular concern. We also find that flash flooding will impact shorter rivers and streams, both of which have the most rapid response times associated with extreme rainfall events. In mountainous terrain, debris flow and boulders carried along with the flooding cause damage. In addition, the rapid/high volume run-off can cause changes in the river channel morphology, causing flooding outside of the original channel. Finally, blockages (as at bridges) can divert rivers through populated regions.

Flash flood examples from France and Belgium are addressed on the following slides.



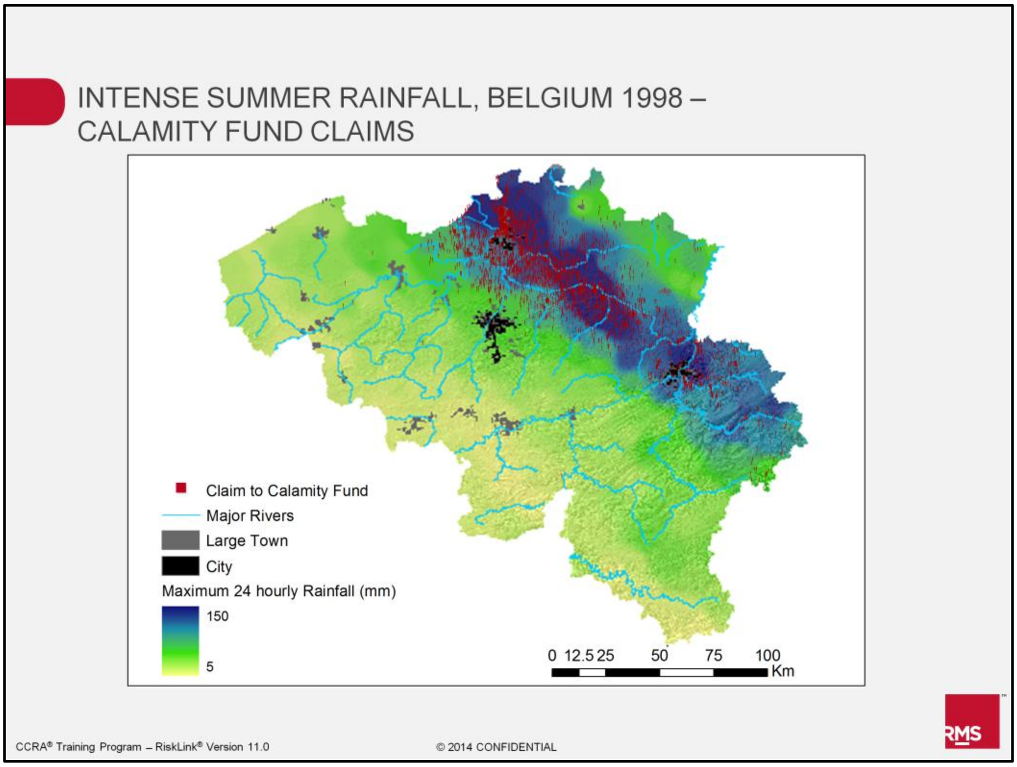
Flash flooding events in southern France occur in the late summer when the atmosphere is warmer and has a much greater capacity to carry water vapor. As a result there is a greater potential for concentrated rainfall over smaller regions.

Shown on this map is the regional extent of two flood events that occurred in September 1992. September is the time of year when the sea surface temperature is highest and the evaporation rates are highest, thus increasing the potential for very high rainfall events around southern France.
One event on the 26th of September (shown in green) is close to the Pyrenees in a concentrated region of about 100 kilometers across. In contrast, the flooding for the 22nd of September event (shown in red) is distributed along two separate localized regions.

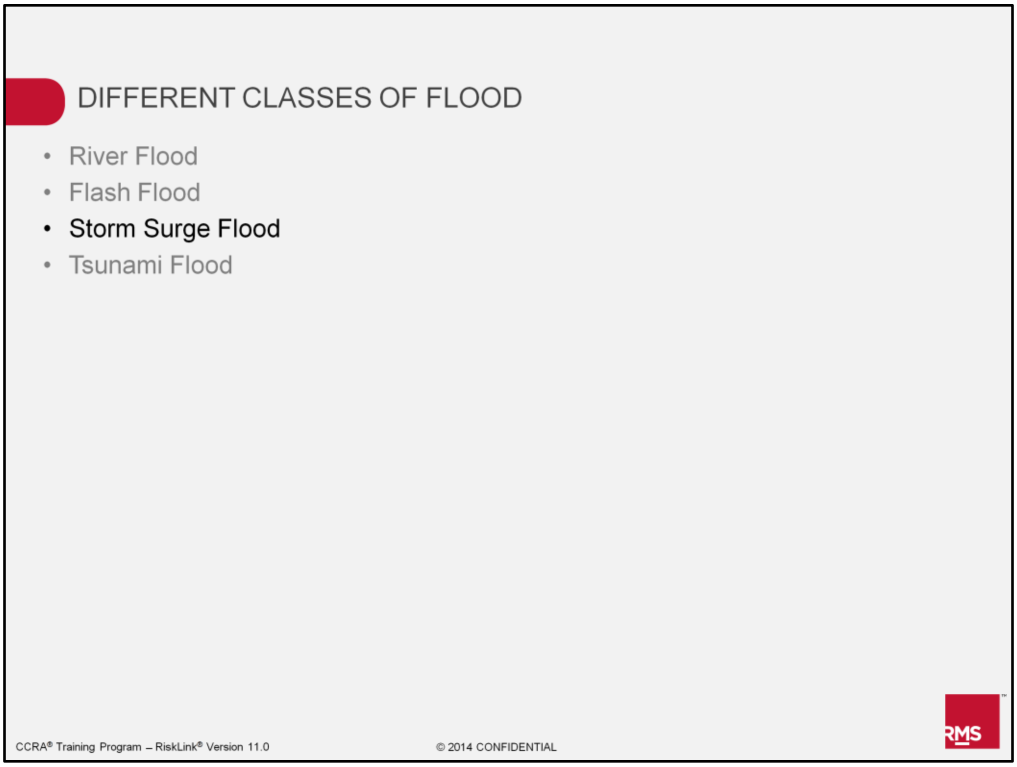


Another example of northern Europe flash flooding occurred in 1998 when a stationary front ran across Belgium and the southern part of the Netherlands. Very high rainfall rates of up to 150 millimeters, or six inches, were recorded in a 24-hour period. This is depicted by the area of dark blue.

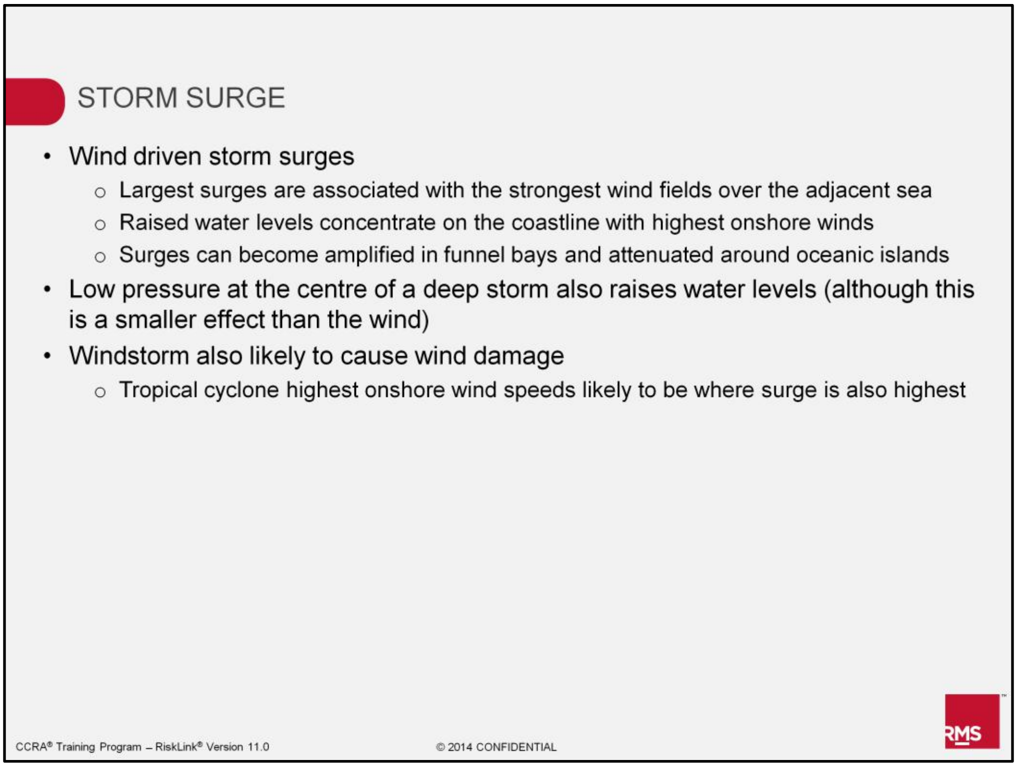
As a result, there was very widespread flooding to many properties. These properties were impacted by both river flooding and sheet flow outside the river channels in areas which were directly impacted by the extreme precipitation run-off across land.



This map shows the locations of the claims made to the Calamity Fund that existed at the time in Belgium. This was not standard flood insurance, however, it provided a mechanism for the refunding of losses due to floods. This map shows where these claims were located in relation to the footprint of the storm. It is clear that the claims were very concentrated and were a function of the magnitude of the rainfall.

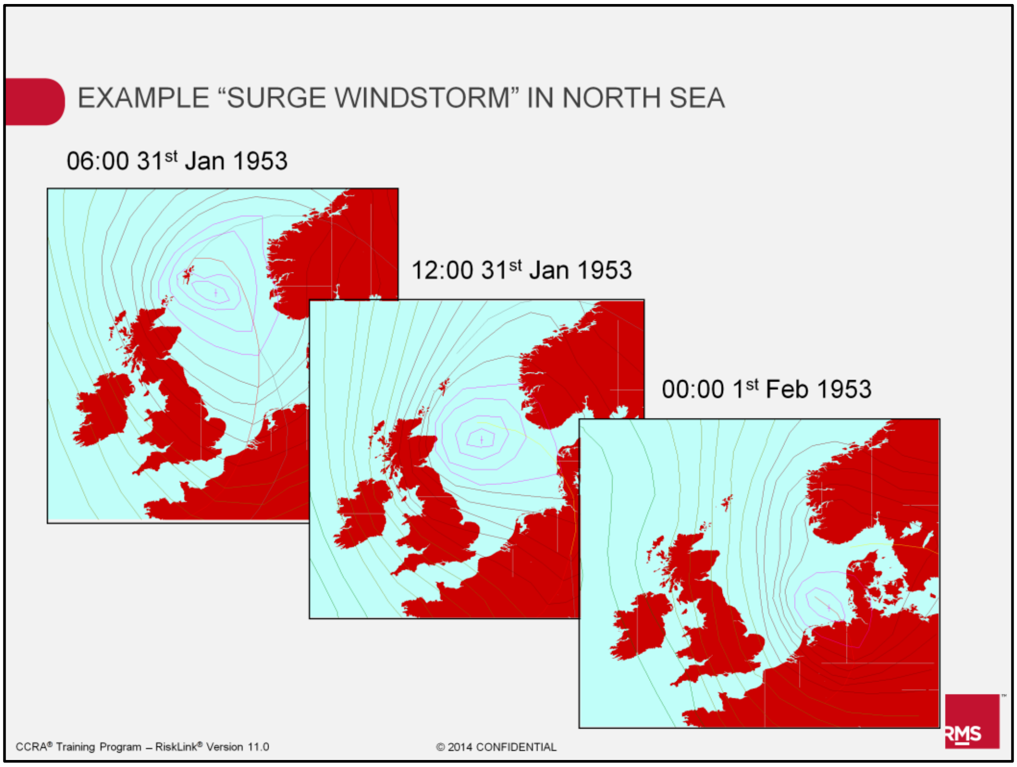


The third class of flooding that will be discussed is storm surge.



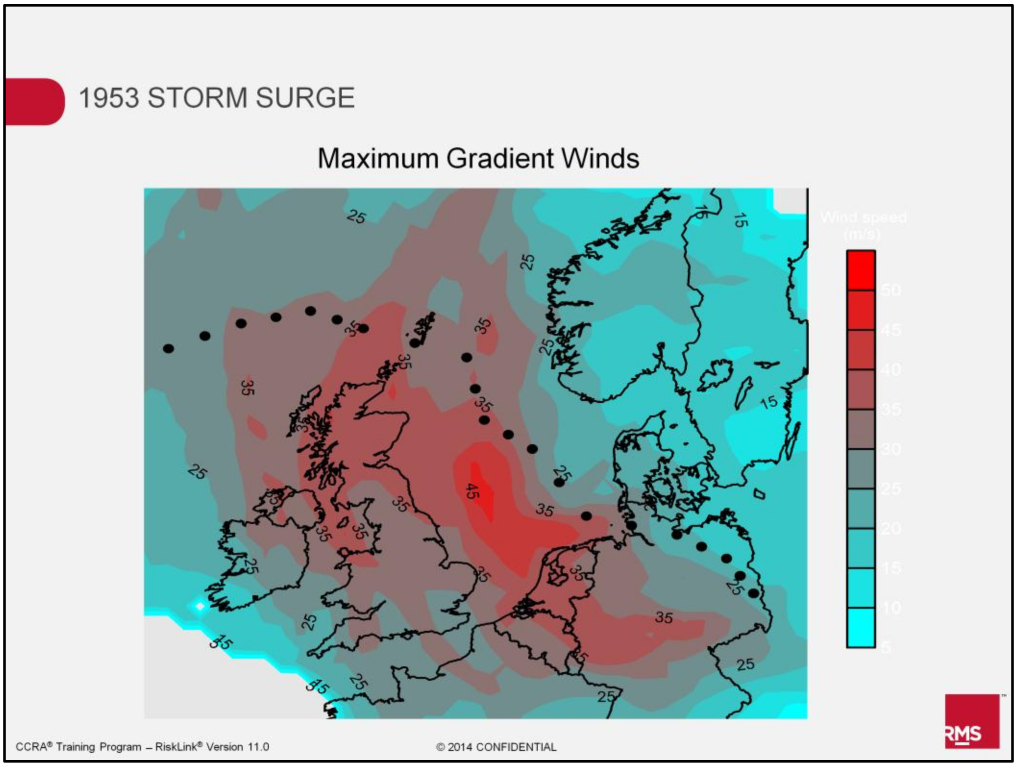
Storm surges are driven by storm-related wind. Since wind-driven storm surges are associated with the strongest wind fields over the adjacent sea, the stronger the hurricane or the windstorm, the higher the surge that is created by it. That means that very often the coastline that has the highest storm surge is also the one which experiences the highest wind speeds. As a result, it may sometimes be difficult to determine whether damage was caused by the wind or by the storm surge.

Storm surges can be driven by any large windstorm, including both tropical cyclones and extra-tropical cyclones. The level of the sea is slightly raised during these strong cyclonic storms due to lower pressure at the center of the storm. This has a much smaller effect than the impact of the high winds blowing across the surface of the sea causing a temporary regional rise in sea level.

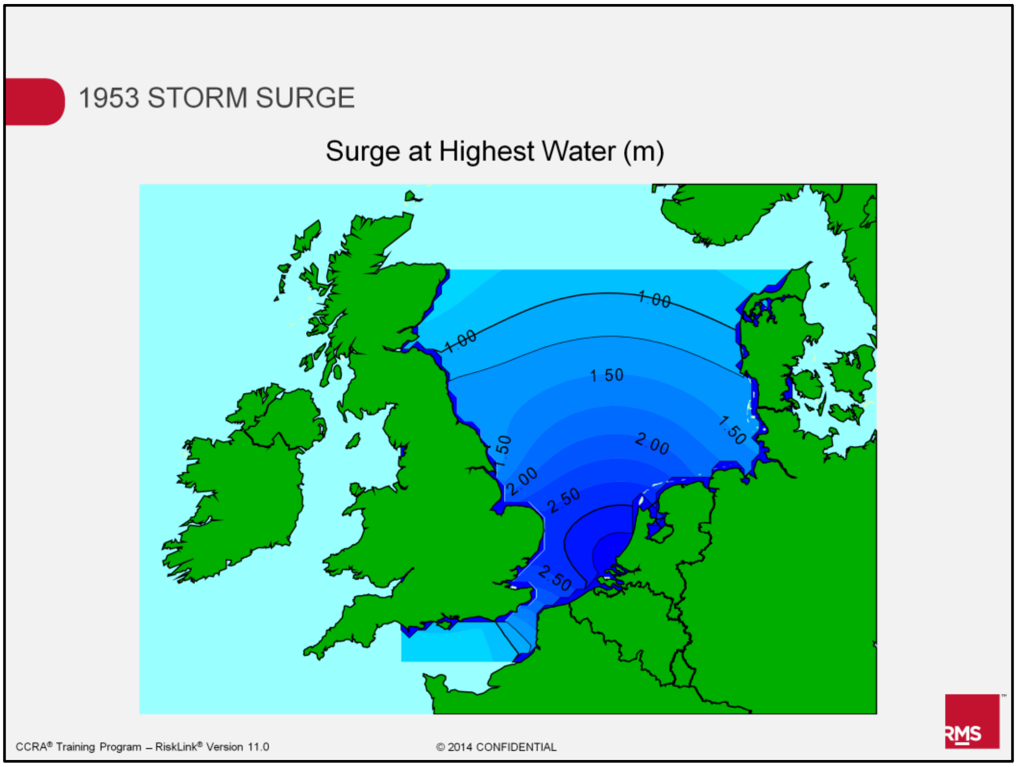


A famous windstorm at the end of January and into the first day of February in 1953 caused storm surge in the North Sea and eventually impacted the eastern coast of the U.K. and the southern part of the Netherlands. The surge was caused by a deep low pressure system moving south along the North Sea. The maps shown here depict lines of equal pressure, or isobars. The lowest pressure is at the center of the storm depicted by a closed circle. The map provide snapshots of six-hour intervals. The first map shows the center of the storm at the area around the Shetlands as it was intensifying. The next two maps show successive locations as the low pressure center moved off toward the southeast corner of the North Sea. The highest winds are on the south side of the track.

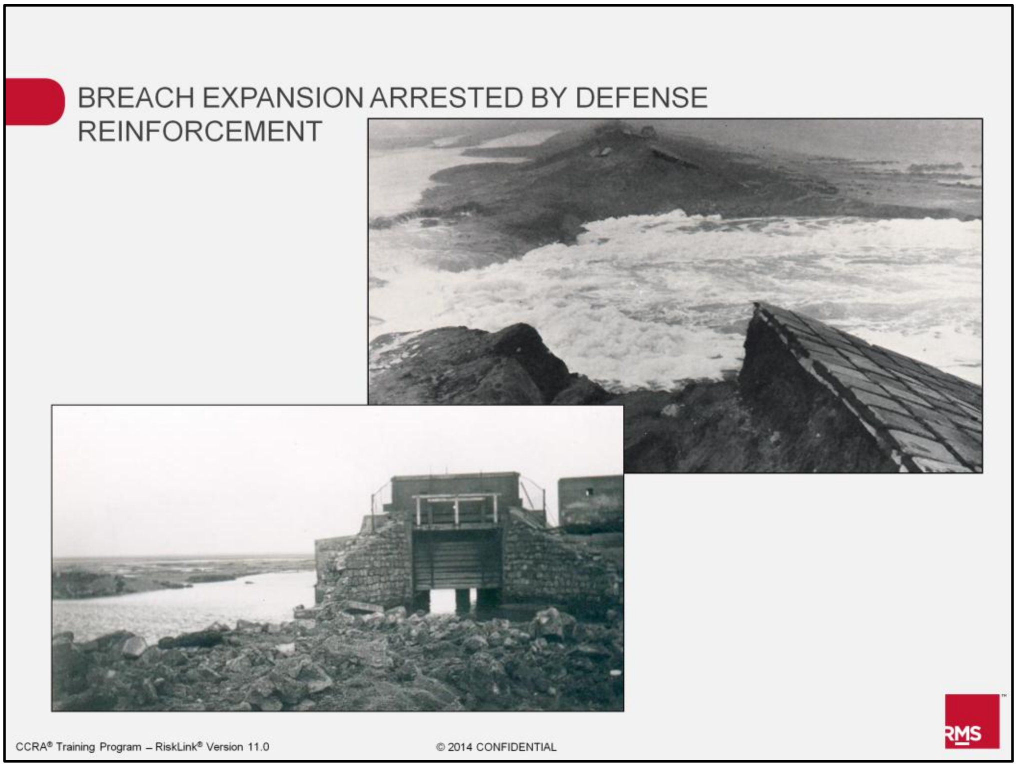
The storm was being squeezed up against a very strong anticyclone located to the west of Ireland causing very high wind speeds along the western side of the North Sea, as depicted by very tight isobars on the maps. These high winds pushed a mound of water along the eastern coast of the U.K. and down into the southern part of the Netherlands.



Shown on this map are the peak wind speeds modeled for the 1953 event. The dots mark the track of the storm as it moved towards the southeast. The highest wind speeds are located across the western North Sea. They also extended into northeast Scotland. As a result, the storm surge was pushed down the east coast of the U.K. and into the Netherlands. The highest modeled wind speed for this storm is located within the dark red contours and is more than 50 meters per second (110 miles per hour.)



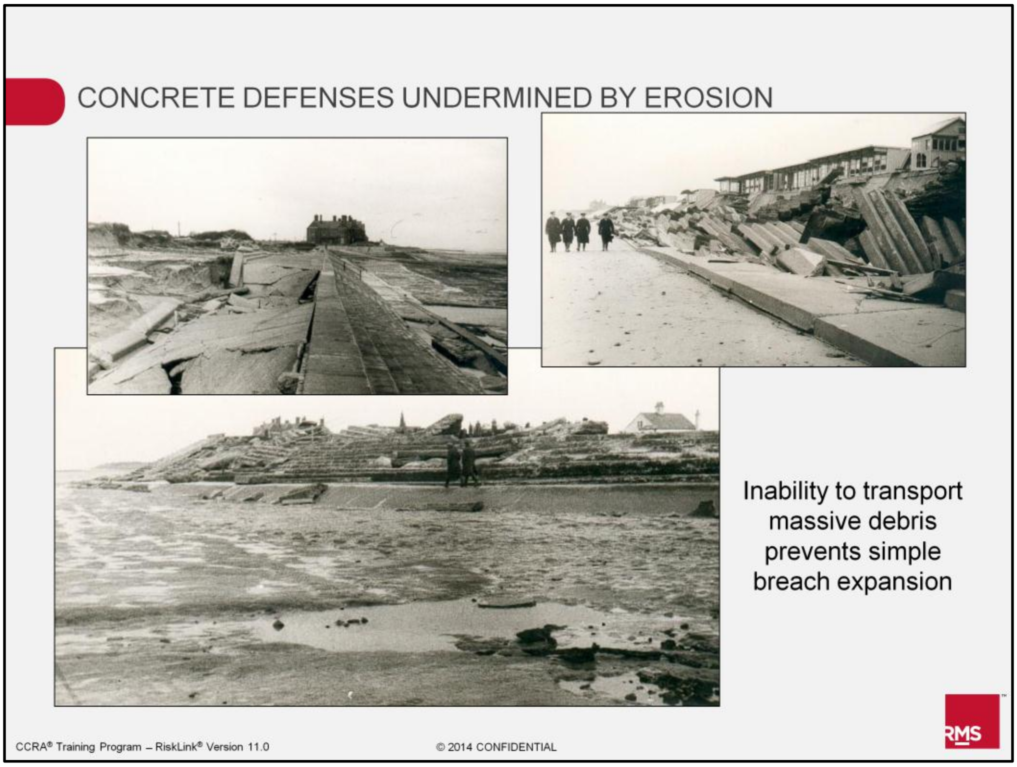
This map depicts the storm surge height which resulted from the 1953 windstorm. The storm surge is contoured in meters. Along the coast of the Netherlands, the highest recorded storm surge was about three meters. The storm surge along the east coast of the U.K. was recorded to be between two and two-and-a-half meters around the coast of East Anglia. The height of the storm surge is lower to the north because the water was not banked up against a coastline. In this sector of the North Sea, the Straits of Dover allow water to flow out into the English Channel. This resulted in lower storm heights compared to the southeast corner of the North Sea near Hamburg where they can reach four to five meters.



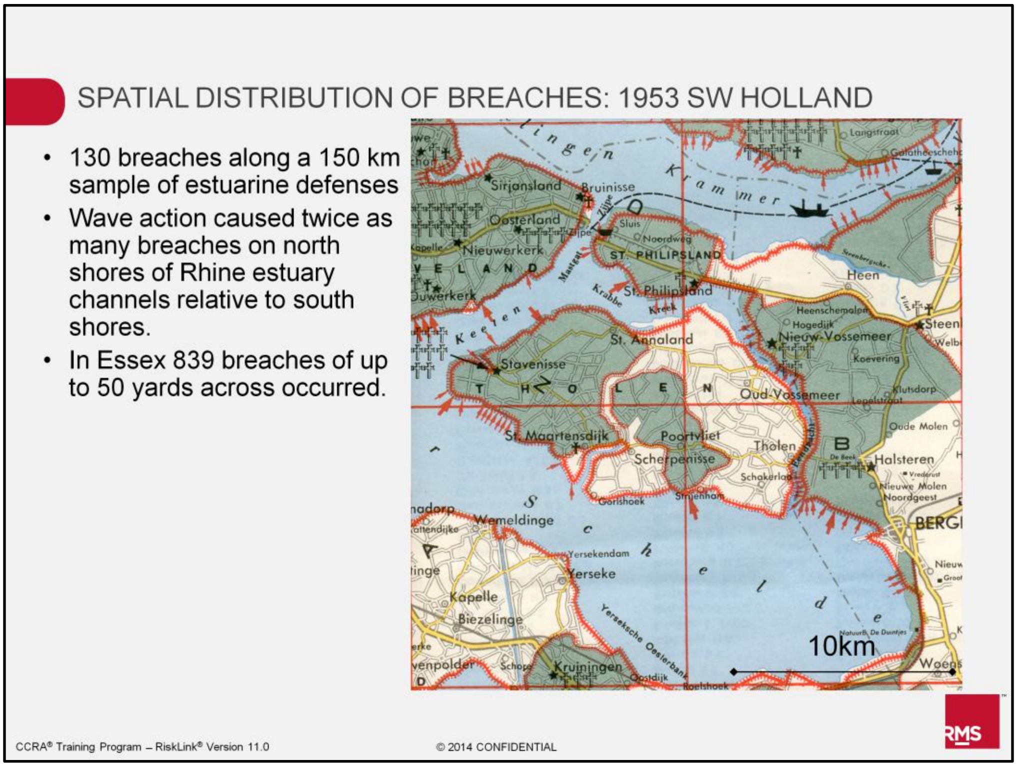
On many coastlines in Europe there are embankments protecting the coastal floodplain. If we are concerned about understanding what determines the extent of coastal flooding, it is important to model the behavior of these defenses when exposed to surge, and determine how they may be overtopped or breached.

Breaching is the process by which a hole forms in the defense, expands, and eventually becomes a major channel through which water can flow into the coastal floodplain. The process of breaching is a function of both the erosive powers of the flowing water and a slumping of the sides along the cut in the defense.

These photos show breached defenses along the east coast of England in the 1953 storm surge. The lower left photo is an example of where some reinforcement on the defense has prevented the breach from simply expanding without any constraint.



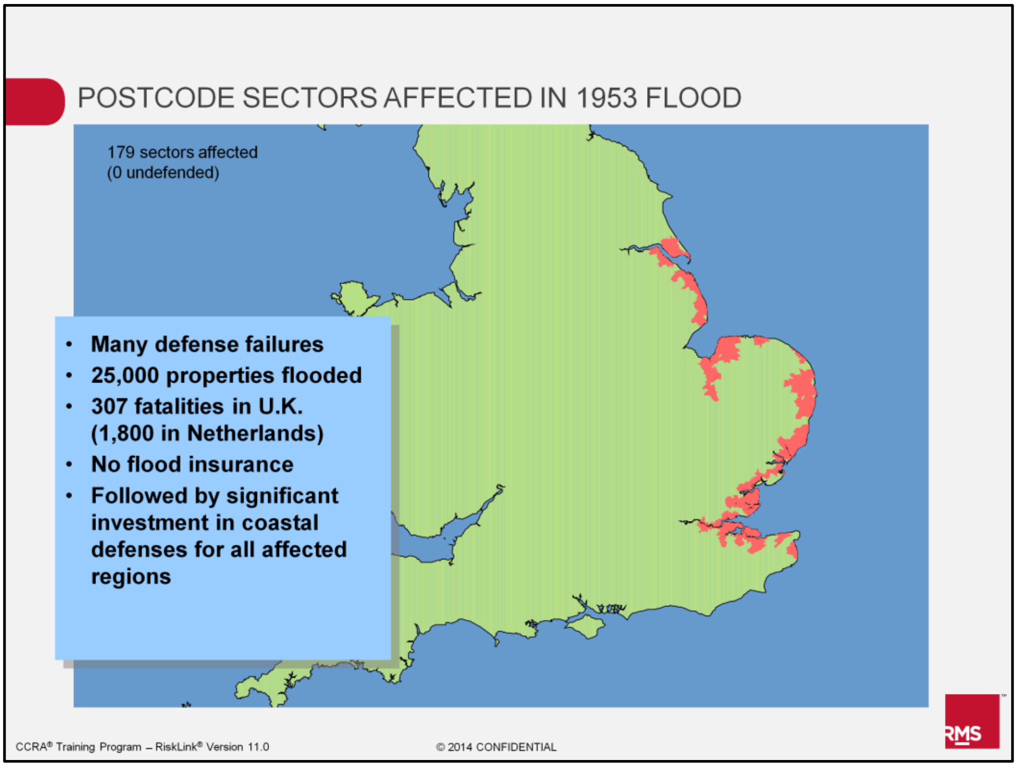
This slide shows more examples of defense breaches resulting from the 1953 storm surge. Unlike the previous slide, a hole in the poorly constructed concrete defenses is not visible. However, the concrete defenses still failed because they were built on sand dunes. The water flowed through the sand dunes and removed the sand which formed the foundations of the defenses, causing the concrete defenses to collapse.



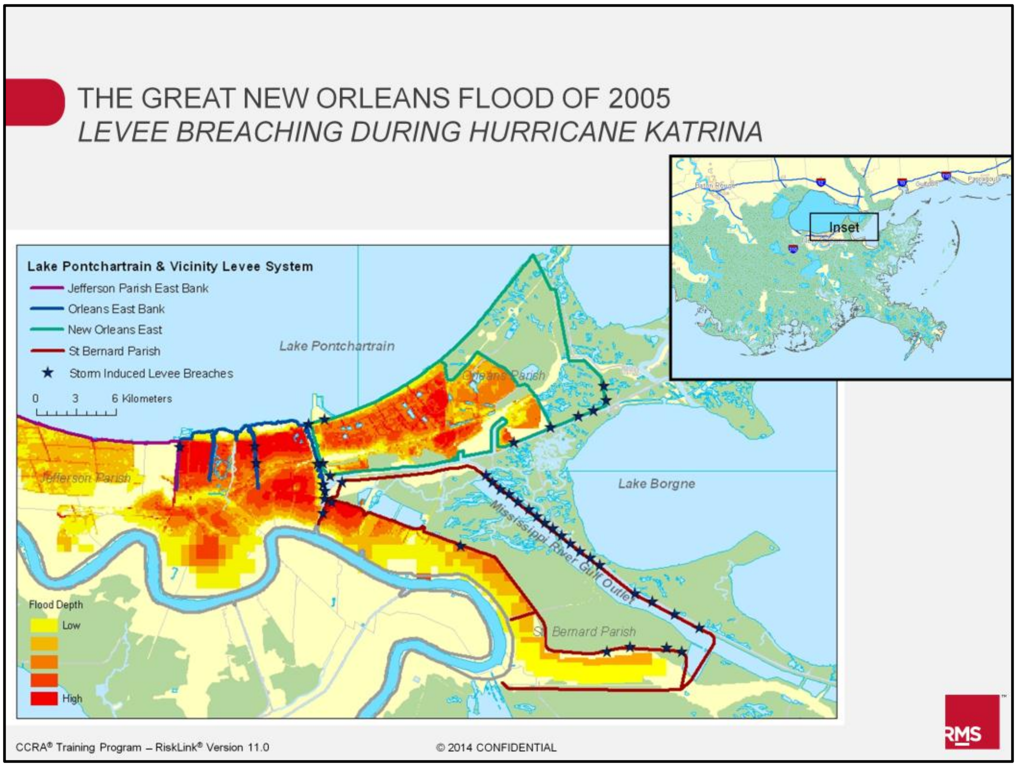
This is a detailed map of the area of the Netherlands which was impacted the worst by the 1953 storm surge. We see here many individual locations where breaches have formed along the defenses. The gray/green represent the areas that were flooded in this event. The crosses mark the locations where large numbers of people were drowned. Each cross represents ten people who were drowned. Approximately 1,800 people died in this event.

We often find in storm surges of this kind that the sections of the defense that are exposed to the open sea are built much more strongly than sections around the estuaries further away from the exposed coastline. Often the defenses which are less well protected are the ones to fail because the combined effects of wave action associated with high wind speeds and elevated water depths accompanying extreme storm surge were not considered when the defenses were constructed. This was also the case in the 2005 flooding of New Orleans in Hurricane Katrina.

In the phenomenon of breaching, once one hole has formed in the defense it is likely that others may form because the defense is built to a consistent height and standard along a long section of the coastline.



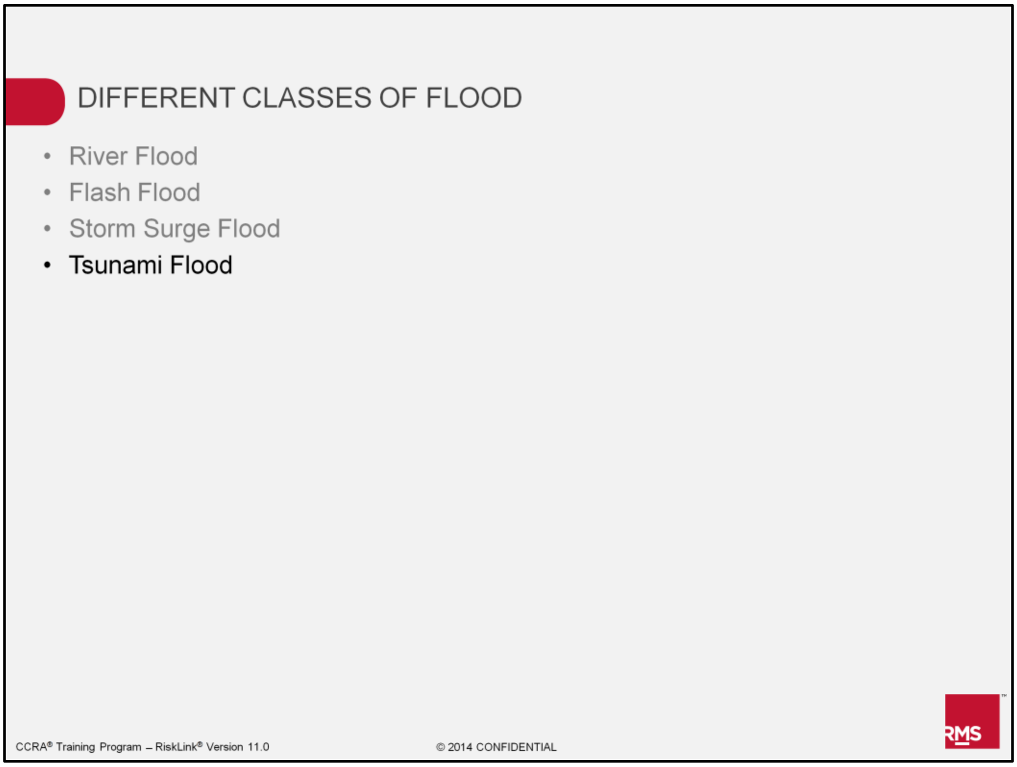
This map shows the 179 postcode sectors which were affected by flooding in the U.K. in 1953. A total of 25,000 properties were flooded. This event is not the largest in terms of the area of property flooded in the U.K. The 1947 river floods that affected a wide area of England and Wales flooded three times as many properties as in 1953. However, the 1953 event is more famous due to the higher casualties from the storm surge related flooding. About 300 people were drowned in the U.K. when the flooding occurred without warning in the middle of the night. There was no flood insurance at this time. The flood defenses have since been significantly improved along the east coast of the U.K., although not generally to the standards that currently exist along the coast of the Netherlands.



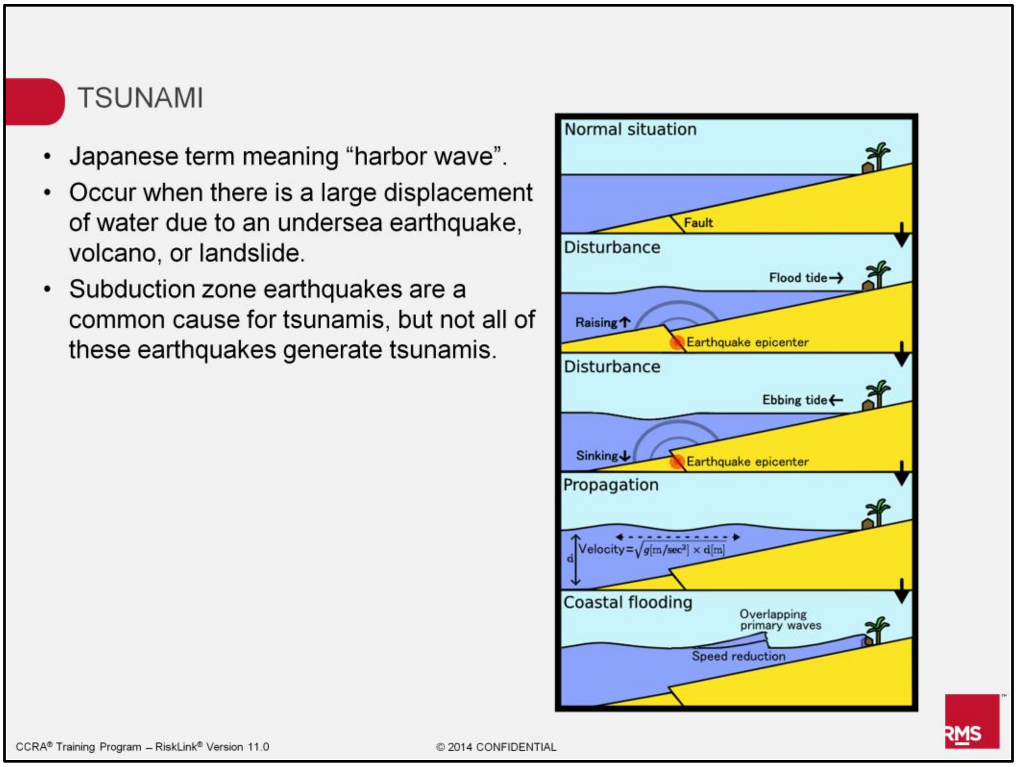
Major levee failures around New Orleans caused the largest surge loss in U.S. history in 2005. Recent studies of Hurricane Katrina storm surge have indicated that it was not only the levee failures of Lake Pontchartrain that caused massive losses, but also the surge in Lake Borgne, which played a much larger role than previously thought in the flooding of New Orleans. The map on this slide depicts the region in southeastern Louisiana, along Lake Pontchartrain and Lake Borgne. Stars indicate storm induced levee breaches or overtopping in Katrina. Peak relative flood depths are mapped from yellow (low) to red (high).

Experts who examined the levee breaches found that most of the damage was not due to poor engineering of the structures, but instead was the result of significant soil-related problems. Some of the most common failure mechanisms are as follows:

- Scour Erosion – Caused by the tidal movement of water. Results in removal of inshore sediments along with the formation of deep holes and/or channels.
- Seepage – The flow of fluid through soil pores. Caused failures on the toe-side of the levees.
- Soil Failure – Occurred when the contact between the levee foundation and the soil exceeded the soil's bearing capacity. This causes sliding on the foundation/soil plane, similar to liquefaction.
- Piping – Similar to seepage. Caused by the erosion of the soil starting at the exit point of the seepage. Continues up-gradient producing a channel, which may increase rapidly, causing catastrophic failure of the levees.



The last class of flooding that will be discussed are those caused by tsunamis.



Tsunami is a Japanese word which means a wave in the harbor. Tsunamis occur when there is a significant large scale displacement of the sea floor. This displacement could be a function of a sudden fault movement, the result of a volcanic eruption, a collapse of a volcano, a landslide down the side of a volcano, or it could be a result of a submarine slide, where a landslide takes place along the continental margin.

Tsunami waves often impact locations which are not exposed to ordinary wave action and therefore are usually protected against the extreme waves that may turn up in storms. The function of a harbor is to protect boats and properties from exposure to ordinary wind-driven waves. But these harbors, it was found, are exposed to these infrequent waves which have a much longer period, meaning a much longer time between the arrival of one high water level to the next high water level than in wind driven waves. As a result, the tsunami wave has the greatest impact in an area which otherwise is sheltered from ordinary wind-driven wave exposure.

The most common cause of large tsunamis is sudden sea floor displacement along subduction zone plate boundaries where an oceanic plate is passing underneath a neighboring continental plate. This motion is typically along a low-lying or low-angle fault zone which is subject to very severe and infrequent major earthquakes. The length of the fault rupture may be hundreds of kilometers, so the displacement of the sea floor may be over a very broad region. The displacement may also be a few meters in vertical extent. The size of the tsunami is a very simple measure of the overall volume of displacement of the sea floor. A very long fault with a large movement on it can generate the largest tsunamis. The largest tsunamis are the ones which will travel over the greatest distances and have the broadest impact.

TSUNAMI DAMAGE

- Damage is caused by the huge mass of water behind the initial wave front, as the height of the sea keeps rising quickly and floods powerfully into the coastal area.
- Weight of water is enough to pulverize objects in its path, often reducing buildings to their foundations and scouring exposed ground to the bedrock.
- Large objects such as ships and boulders can be carried several miles inland.

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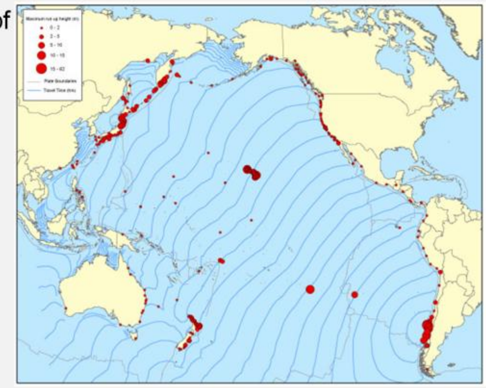
As the wave associated with the tsunami travels onto the land, it moves at a high velocity, often more than ten meters per second. As a result, it can carry debris with it and can cause a large force to be exerted against the side of buildings in its path. It is this pressure which predominantly causes the damage. Many buildings, especially wood frame buildings, do not have the strength to withstand rapid water movement through them. This would be the case in a coastal floodplain subject to a tsunami, just as it would be in a mountain village subject to a flash flood.

Flooding can also scour the foundations of the buildings all the way down to the bedrock, causing severe damage or even complete displacement of the structures.

TSUNAMI: BASIN-WIDE WAVES

- Far-field, or "teletsunamis," are those which occur hundreds to thousands of kilometers from the causative source
- Most likely to be caused by great earthquakes (M_w 8.5+) and can be global catastrophes



Map of 1960 Chile earthquake-induced tsunami with travel times (in one hour increments)

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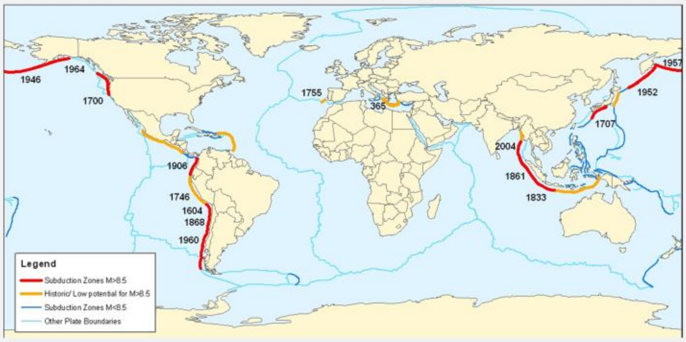
The largest tsunamis are generated by large earthquakes with very long rupture zones and can travel all the way across an ocean, as occurred during the December 26, 2004, Indian Ocean tsunami.

This map shows the extent of the 1960 southern Chile tsunami generated from a 9.5 moment magnitude earthquake, the largest earthquake ever measured. This earthquake was slightly bigger than that of the 2004 Indian Ocean event. The 1960 tsunami waves spread all the way across the Pacific, taking about a day to arrive at the coast of Japan, where they caused significant damage to some villages in estuaries. The tsunami also drowned people in Hawaii.

TSUNAMI HAZARDS

- Tsunamis can occur in nearly any low-lying coastal region.
- Certain regions in the Pacific Ocean have a more significant tsunami hazard by virtue of the subduction zones ringing the Pacific basin.



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Tsunami floods can occur in almost any low-lying coastal region, although they are extremely rare in most regions far from the major subduction zones. In major subduction zone earthquakes along the plate boundaries, in particular around the Pacific but also around the edge of Indonesia passing up across into the Himalayas, such earthquakes may occur every hundred years or so, and therefore the principal global tsunami hazard is associated with these subduction zones.

There are some other sources of tsunamis, besides major submarine fault systems. One of these is volcanic collapse. These events only occur every tens or hundreds of thousands of years on a given island volcano after many individual eruptions which may be hundreds of years apart have increased the size of the island. This map shows the locations at greatest risk of tsunamis. You can see that the location of the 2004 tsunami running up through the Indian Ocean is on a fast-moving plate boundary which has some of the highest tsunami hazard. Such tsunami hazard is also found around the west coast of South America. Finally, the region adjacent to the Cascadia subduction zone from northern California, along the coast of Oregon and Washington State into Vancouver Island and around the coast of the Aleutian Islands, Alaska, and Japan is also at high risk to tsunami hazard.

CORRELATING FLOOD RISK WITH OTHER PERILS

- River flood – sometimes linked to tropical cyclones
- Flash flood – can be linked with tropical cyclones or tropical air mass in an extra-tropical cyclone (ETC)
- Dam/defense failure – can be linked with earthquakes in seismically active regions
- Storm surge – strong overlap with windstorm (tropical and extra-tropical) and wind related damages
- Tsunami – strong overlap with major undersea earthquakes, especially subduction events

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As was mentioned at the beginning, flooding may often occur at the same time as other sources of loss. With river flood, for example, tropical cyclones are very effective at transporting large amounts of moisture and typically can give rise to extreme rainfall amounts. These extreme rainfall amounts may be 15 to 30 centimeters (6 to 12 inches) over mountainous areas. They can also be much higher than that. So it is quite common to find river flooding in association with a tropical cyclone and with tropical cyclone wind-related damage. The areas which are impacted by river flooding tend to be somewhat inland and in mountainous areas, so it is less common to find the highest wind damage in the same geographical area as the highest river flooding damage.

Flash flooding can be linked with any disturbance where there are high levels of atmospheric moisture. In northern latitudes it is more often associated with summer thunderstorms or other classes of complex convective storms. It can also be linked to tropical cyclones in mountainous areas.

Dam defense failures can be linked not only to extreme precipitation but also to earthquakes. They are relatively rare, but a number of earthquakes in urban areas have come close to cutting through neighboring dams, in particular in the region around Los Angeles. It is thus possible to have situations where flooding may follow an earthquake.

With storm surges there is a strong overlap with the area of highest wind speeds in a storm and there may be situations, particularly in tropical cyclones, where it may not be so easy to differentiate between storm surge and wind-related damages. Therefore, even though flood may not be an insured coverage, quite commonly there may be situations where flood losses get paid out within standard insurance coverages because it has not been possible to state categorically that flood was the only source of loss.

The majority of tsunamis are generated by major undersea earthquakes. If there are coastal areas or islands located in the vicinity of the fault rupture then it is common that the areas impacted by the tsunami may also have experienced damage due to shaking.

PERIL ANATOMY
LEARNING OBJECTIVES

- Four principal classes of flood events:
  - River flood, flash flood, storm surge, tsunami
- Spatial concentration of flood loss events
  - Multiple rivers may be affected in the same event
  - Extreme rainfall floods are concentrated
  - Surge follows the storm track (may affect multiple island coastlines according to onshore winds)
  - Most tsunami impacts are local – except for rare regional “megatsunamis”
- Not all flood plains are so recognized

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This slide summarizes the key concepts from Unit 1. Review the summary to make sure all key concepts are clear to you before continuing on to Unit 2.