

This talk is part of an Association of Metropolitan Water Agencies 2017 Water Policy Conference general session panel including this talk, EPA on drinking water regulatory outlook, Lead Service Line Collaborative on replacing lead water service pipes, and Water for People on accelerating progress toward ending the global water crisis.

Date: Monday 27 Mar 2017

Time: 1400-1600 Eastern (Panel)

Location: Washington court Hotel, 525 New Jersey Ave NW, Washington, DC 20001

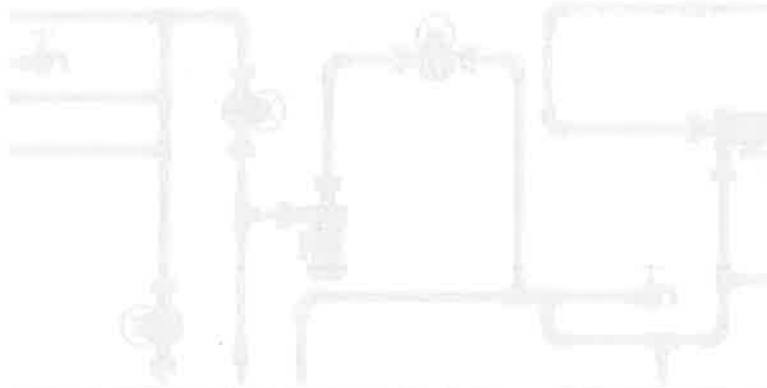
Description:

***Let's Talk About Reservoirs and Rule Curves***

Dr. Kate White, Lead for Climate Preparedness and Resilience Community of Practice at the U.S. Army Corps of Engineers will discuss the work the Corps is performing to better understand reservoir sedimentation, rule curves and the impacts of climate change on the management of water supply. The discussion will also cover information about reservoir allocation processes and how AMWA members can better engage with the Corps on reservoir issues.

**John W. Gardner (1912-2002, HEW Secretary 1965-1968)  
said in 1961:**

**"The society which scorns excellence in plumbing as a humble activity and tolerates shoddiness in philosophy because it is an exalted activity will have neither good plumbing nor good philosophy: neither its pipes nor its theories will hold water."**

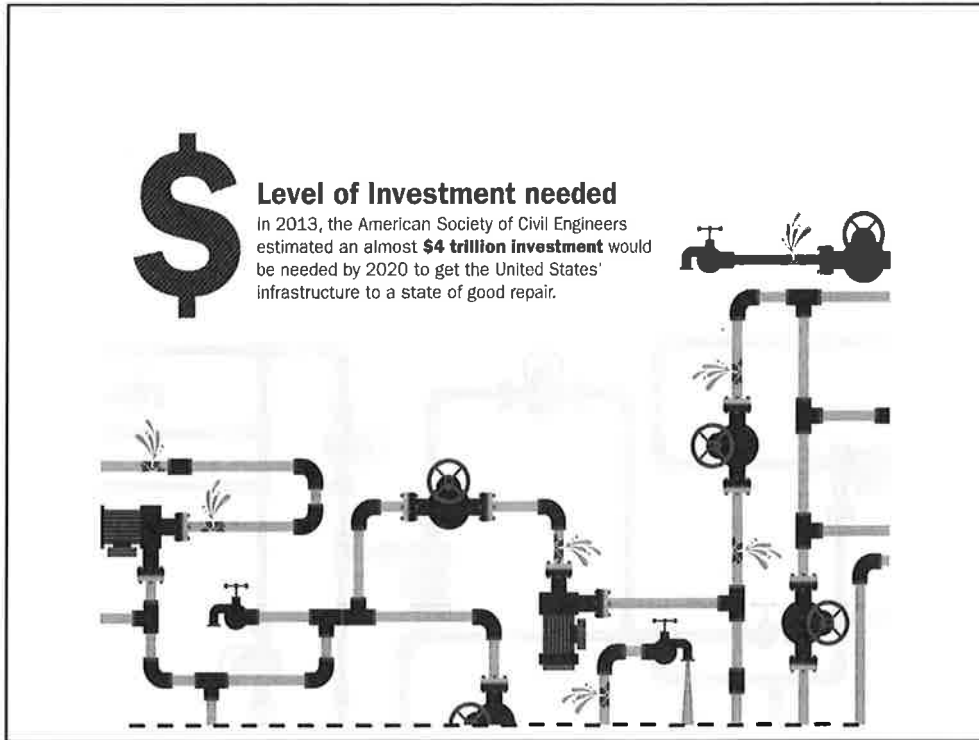


Let's begin this panel session with a little thought about the state of water infrastructure in America, represented here as ideally a complex network that has all the proper working parts.

But, as John W. Gardner said in 1961 on the topic of excellence, the work we do to supply water is critical to the Nation – we should aim in excellence for our plumbing.

John W. Gardner also said in a 1965 speech that "What we have before us are some breathtaking opportunities disguised as insoluble problems."

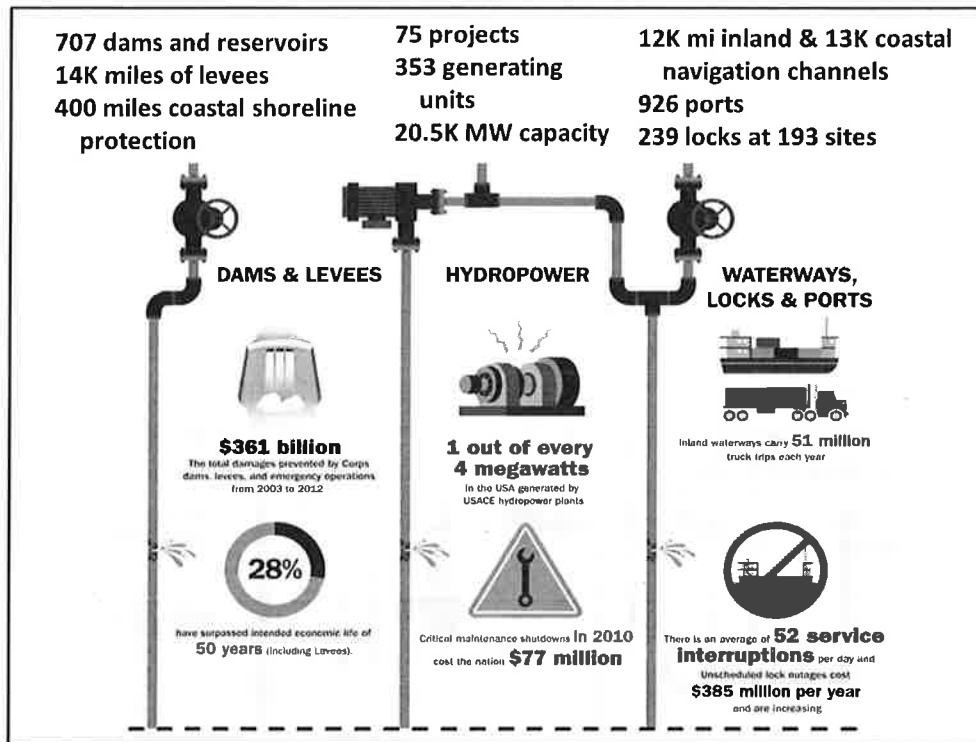
And that's exactly what our water infrastructure problems are: opportunities.



Unfortunately, our plumbing has not been supported to excellence, though we know staff in the public and private sectors are working very hard to keep the systems going.

Despite our collective best efforts, we are springing some links.

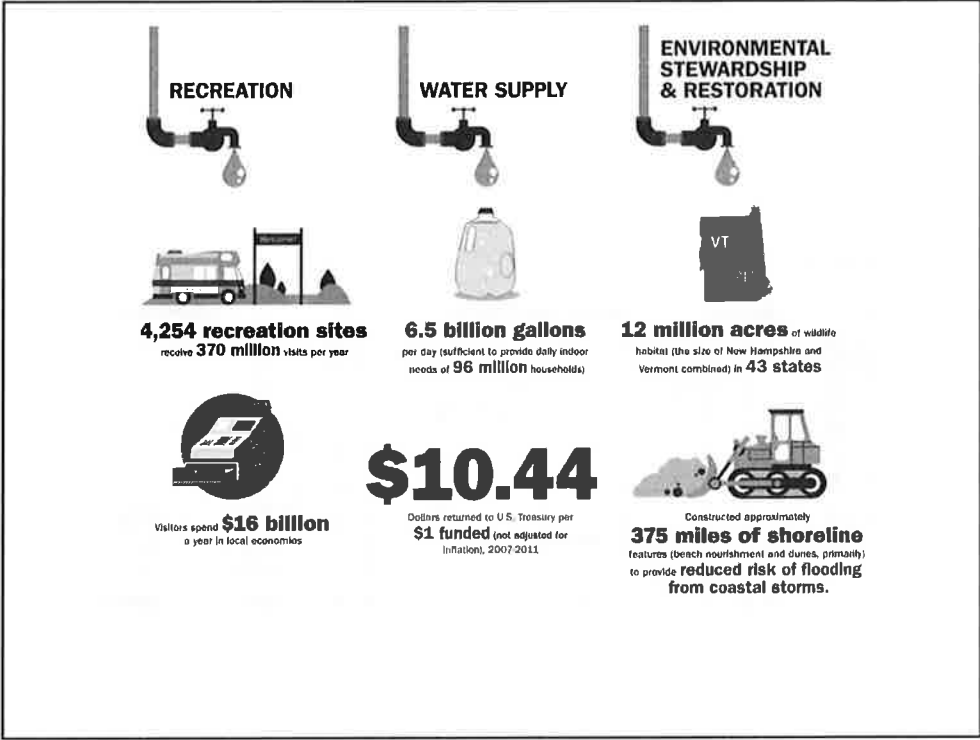
And I would include the Corps in the leaky pipes issue. So instead of the traditional slide on what the Corps does in water infrastructure, I'll present our missions and operations in this way.



So, what is the universe of USACE water management, and what is the value?

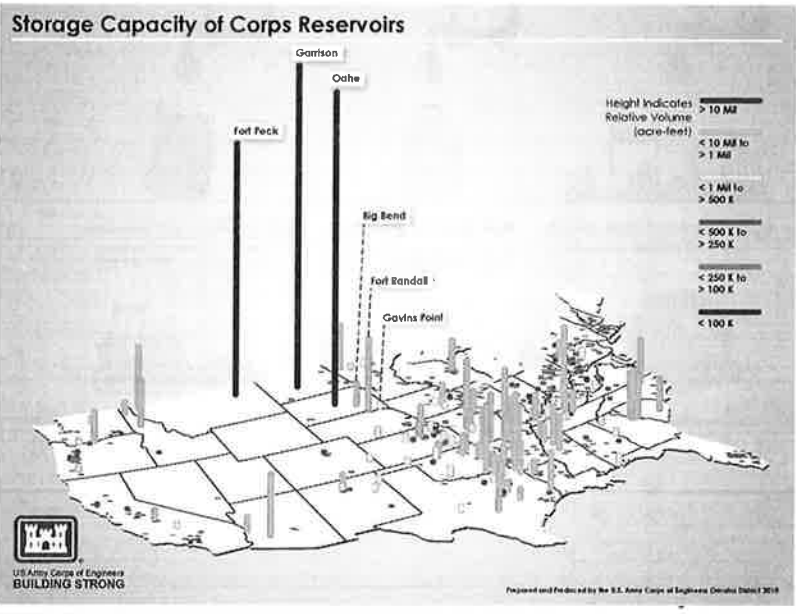
Well, we have a long-standing mission in flood risk management. As part of this we've got over 700 dams and reservoirs over 14,000 miles of levees that we oversee, and another 400 miles of coastal shoreline protection.

Navigation is a really big mission for the USACE. As part of this, we operate and maintain 12,000 miles of inland navigation channels and 13,000 miles of coastal navigation channels, 239 locks at 193 sites, and 926 ports.



And this brings us to the water supply, which is probably what you really want to hear about.

# RESERVOIRS: VOLUME



This graphic shows the amount of storage in USACE reservoirs.

And where this storage is located.

## RESERVOIRS AND RULE CURVES: LITTLE KNOWN FACT

- **Section 7** of the Flood Control Act of 1944\* as amended, gives USACE the authority to manage the flood control pools during a flood event at reservoirs constructed wholly or in part with Federal funds which have allocated storage for flood control or navigation purposes
- Excludes reservoirs in the Tennessee Valley Authority, except in cases of danger from floods on the lower Ohio and Mississippi Rivers
- Section 7 authorization allows for the coordinated management of flood peaks and reduces the chance that multiple small peaks combine to form a larger flood event

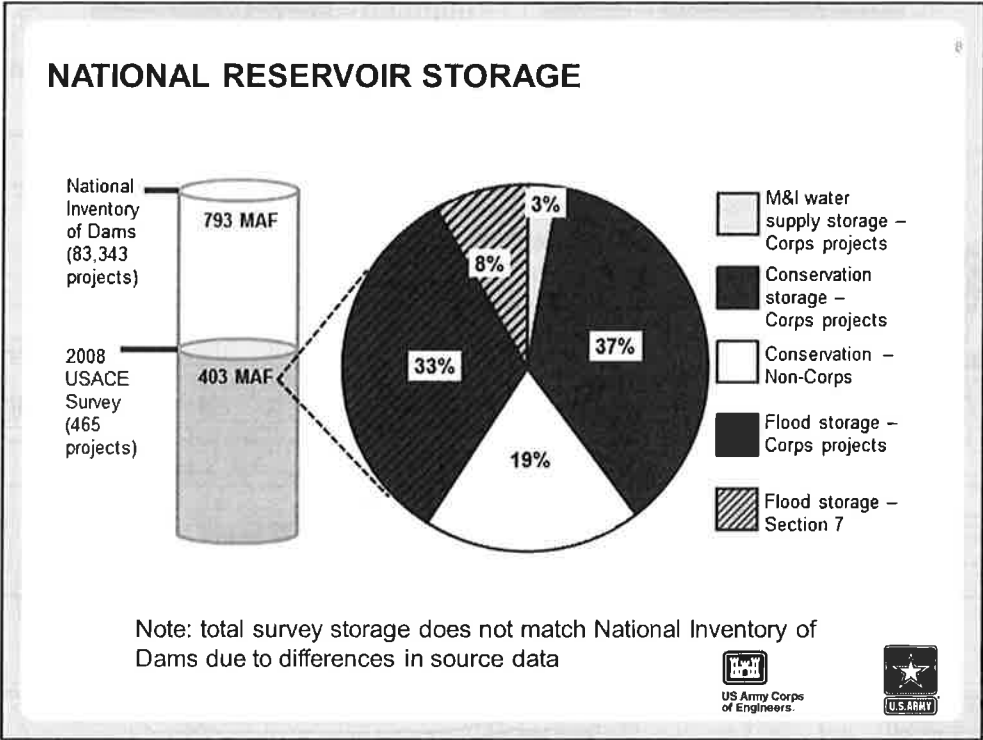


■ Section 7  
■ USACE



\* 16 U.S.C. 460d; P.L. 78-534, December 22, 1944; 58 Stat. 890, 33 U.S.C. 790

While we are talking about reservoirs and rule curves, I want to point out that it is not only the Corps that has flood control storage. Many other reservoirs have this storage also, which is under the jurisdiction of the USACE during floods.



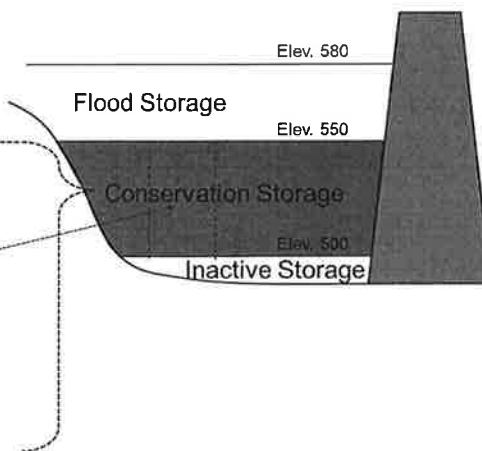
This gives you an idea of how the storage breaks down nationally.

So about half Corps, and maybe 40% flood storage.

## RESERVOIRS AND RULE CURVES: STORAGE

### Authorized Purposes:

- Flood Risk Management
- Navigation
- Hydroelectric Power
- **Municipal and Industrial Water Supply**
- Irrigation
- Water Quality
- Fish and Wildlife
- Recreation
- Other



Like other Federal reservoirs, USACE reservoirs provide authorized purposes.

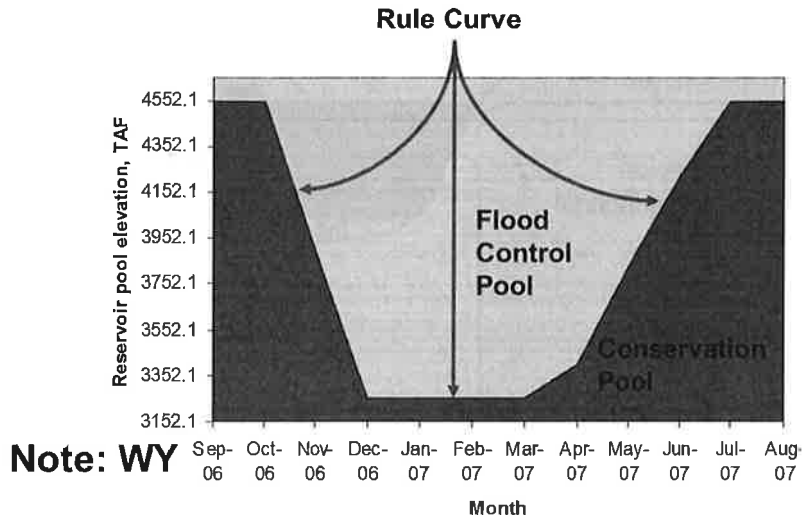
Most purposes served by Corps multipurpose reservoirs fall into eight general categories:

flood risk management,  
navigation,  
hydroelectric power,  
M&I water supply,  
irrigation,  
water quality,  
fish & wildlife, and  
recreation.

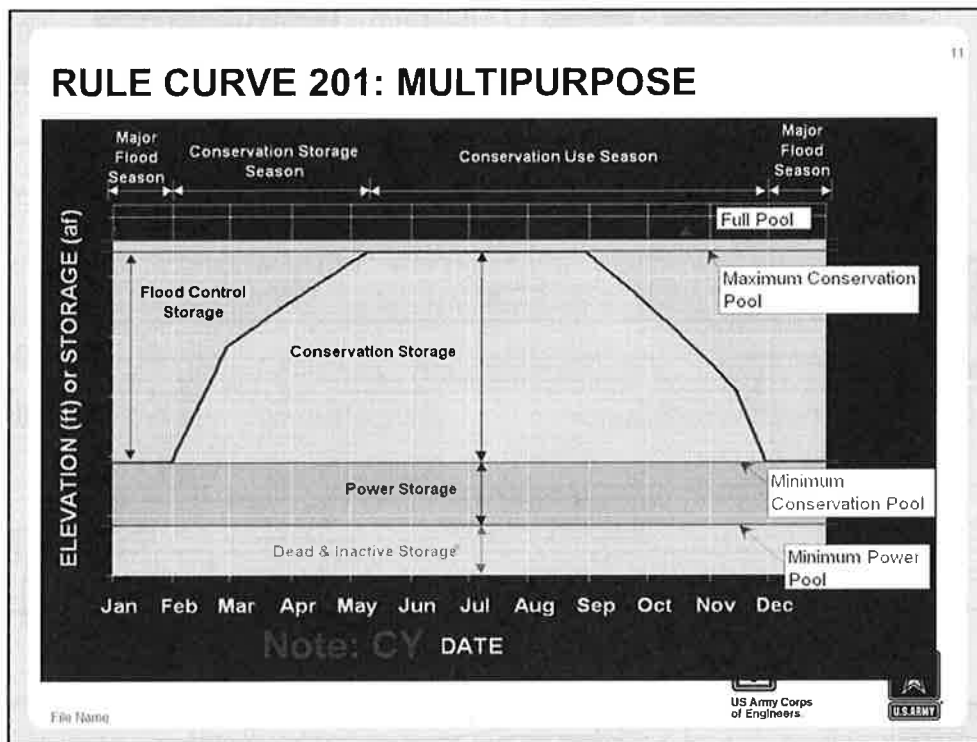
Some projects may also have other specifically authorized purposes that don't exactly fit these categories. Examples include: sediment control, low flow augmentation (without stipulation to a specific purpose), water conservation (without stipulation to a specific purpose), and groundwater recharge. (source: HEC PR-19 Report, "Authorized and Operating Purposes of Corps of Engineers Reservoirs," 1994)

### RULE CURVE 101: SIMPLE

Flood Control Pool: Storage required for authorized flood control purposes  
Conservation Pool: Storage for non-flood control purposes

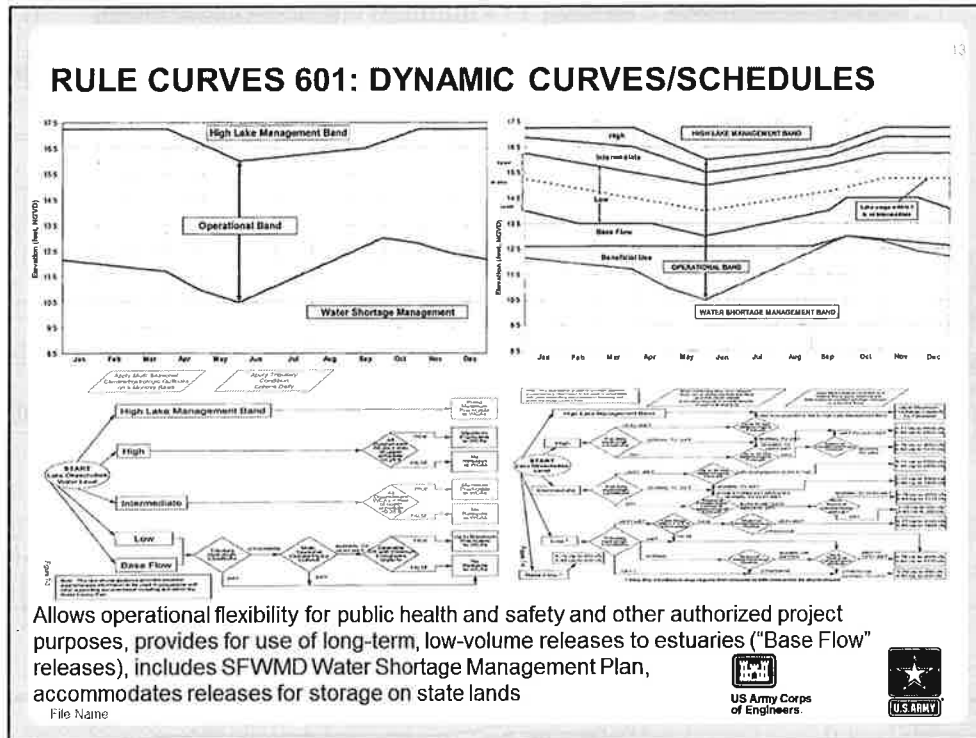


So let's get to the rule curves....



The rule curve gets a little more complicated for multipurpose projects. This example shows a rule curve for a reservoir with flood, power, and other authorized conservation purposes.





This one might be a post-graduate rule curve. Here, there are multiple flexibility points: public health and safety, estuaries, water district, and releases of various kinds.

The process to determine quantity, timing, and duration of the potential releases from Lake Okeechobee includes consideration of various information, including but not limited to:

- Central and Southern Florida Project conditions
- Historical lake levels
- Estuary condition/needs
- Lake ecology conditions/needs
- Water Conservation Area water levels
- Stormwater Treatment Area available capacity
- Current climate conditions
- Climatic forecasts
- Hydrologic outlooks
- Projected lake level rise/recession
- Water supply conditions/needs

## RESERVOIRS AND RULE CURVES: FLEXIBILITY

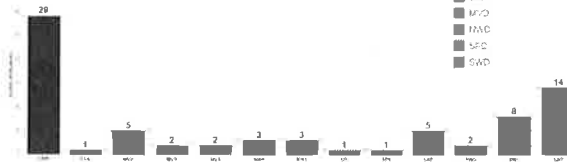
- USACE water operations are governed by a flexible system of
  1. Water control manuals
  2. Reservoir rule curves
  3. Drought contingency plans
  4. Deviations from authorized water control
    - Planned
    - Unplanned
    - Short-term
    - Long-term
    - Emergency

Flood Control Authorization  
 N  
 Y

Deviation Source  
 Construction  
 Drought  
 Flood  
 Other

Deviation Type  
 Emergency  
 Planned Minor  
 Planned Major  
 Unclarified

Division Abbr  
 LRD  
 MFD  
 HVC  
 SFC  
 SWD



**In 2016, there were 76 deviations issued covering conservation, environmental flows, construction, recreation, and other purposes**

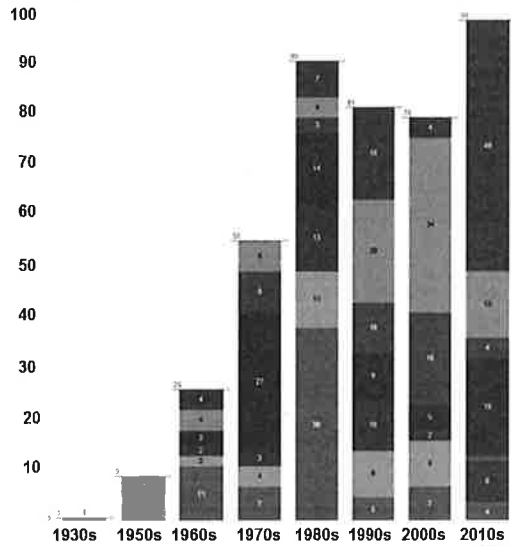


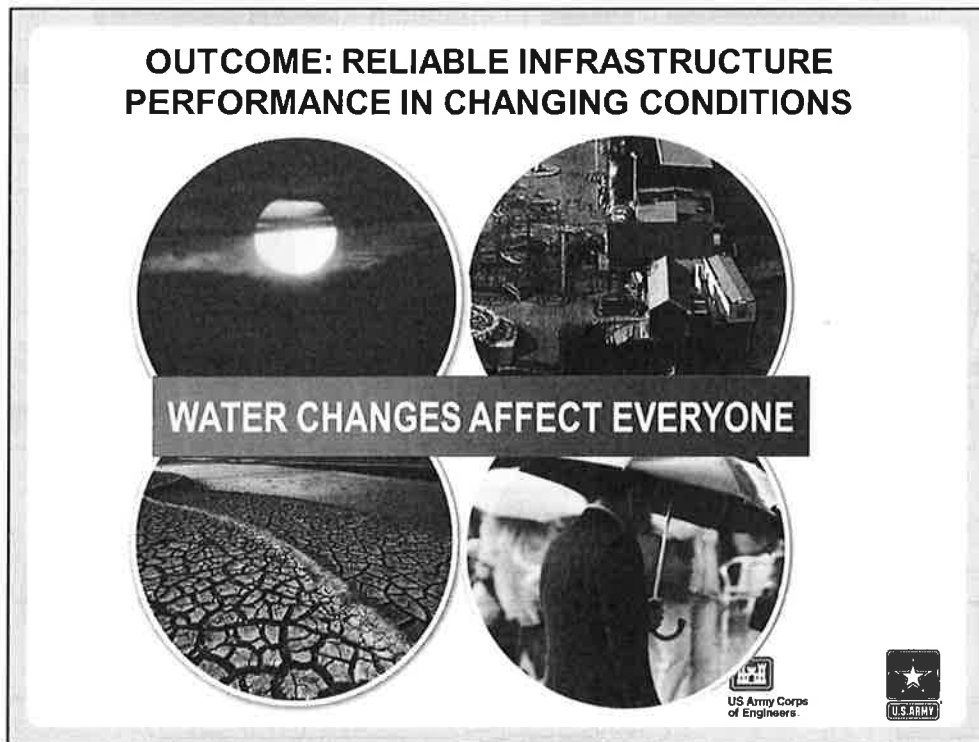
## RESERVOIRS AND RULE CURVES: MANUAL UPDATES

Q: Speaking of water control manuals, I keep hearing how old they are – why don't you update them so they are current?

A: We do update the manuals. But remember, is the entire framework that matters

**Bottom Line: Age is not a metric for flexibility, reliability, quality, performance**





Why do we undertake climate preparedness and resilience activities?

The answer is simple: our desired outcome is reliable infrastructure performance in changing conditions.

As you know doubt are aware, the hydrologic cycle is very sensitive to changes in temperature, which drive rainfall and runoff. Therefore, changes in climate drive changes in water.

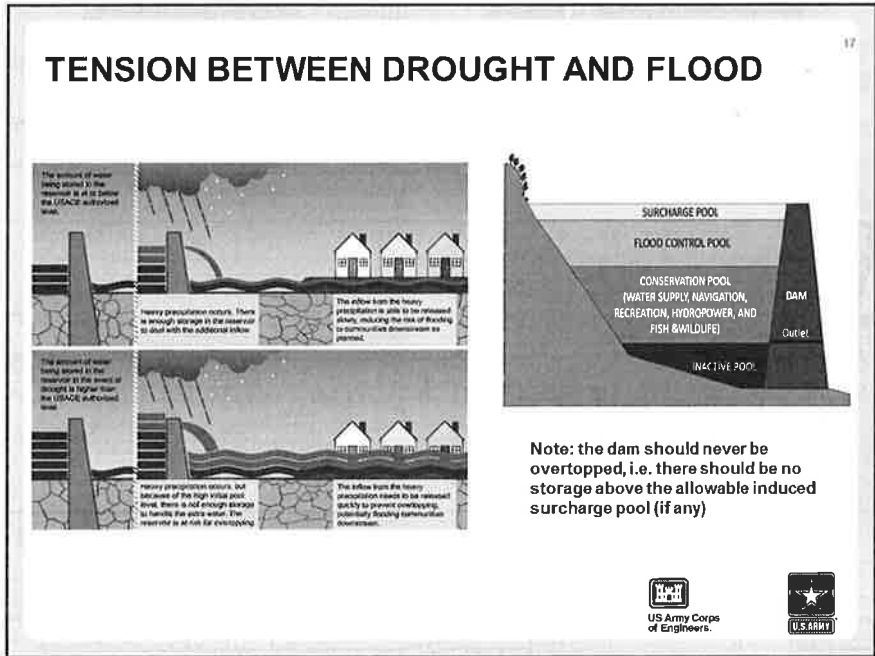
I'm going to start here by talking about the climate changes in the context of the supporting evidence.

Starting at the upper left and moving clockwise are the projected climate changes with the most supporting evidence decreasing as we go around. These are: heat waves (most supporting information), coastal flooding (primarily due here to changes in local sea level), extreme precipitation events, and severe drought.

There are other changes for which we have less supporting evidence, such as hurricanes and tornadoes. Though these events can be catastrophic, there is much less evidence how and when climate change will impact tornadoes and hurricanes. That doesn't mean we don't pay attention to them – we continue to monitor the evolving science carefully.

And while we can't have perfect knowledge of the future, considering potential conditions can help us begin planning now.

Now, let's consider the cascading impacts that can result from interactions between these changes, because in our complex world, we know that nothing happens in isolation.



Now comes the hard part. It is difficult to manage the balance between flood and drought today – and it will get harder in the future.

The tension between flood and drought arises when we retain flood storage in our reservoir pools despite drought conditions. The flood storage is intended to store runoff from intense rainfall, while releasing water downstream that minimizes damages. Often people see what looks to them like a half empty reservoir and complain that water managers are being insensitive to their needs.

However, we can only encroach so much on the flood storage space before we run the risk of holding so much water that we can no longer avoid flood damages downstream.

This slide provides an example of why it is important to retain empty storage space in federal dams that have a flood control authorization.

The first picture on the left shows the dam at a water level that accounts for flooding (three bars deep to use the cell phone analogy). If a heavy precipitation event occurs, say two bars of runoff equivalent, the dam fills and is able to release additional flow without causing flooding downstream (one additional bar of discharge downstream).

The picture on the right shows the different sections of the reservoir storage.

It is important to know here that the dam must not be overtopped in any case.

CLICK for next picture

But, if there is already water in the flood storage space because we have deviated from the water control plan (second picture with five bars of storage instead of three), that same amount of rainfall (two bars) could cause the pool levels to rise to at or above the flood storage pool. This means that additional discharges from the dam must be made to keep the dam safe, and possible flooding downstream can result (two additional bars of discharge downstream).

**TENSION BETWEEN DROUGHT AND FLOOD IN WATER RESOURCES MANAGEMENT** 10

The amount of water being stored in the reservoir is not enough to handle the extra water. The reservoir is at risk for overflowing.

Heavy precipitation occurs, but because of the high initial pool level, there is not enough storage to handle the extra water. The reservoir is at risk for overflowing.

The inflow from the heavy precipitation is able to be released slowly, including the risk of flooding to communities downstream is reduced.

Heavy precipitation occurs. There is enough storage in the reservoir to deal with the additional inflow.

The inflow from the heavy precipitation is able to be released slowly, including the risk of flooding to communities downstream is reduced.

Cumulative rainfall 20-27 May  
**Heavy Precipitation May-June 2015 Ended Multiyear Drought**  
 Utilizing > 50% Flood Control Storage: 37 projects  
 Utilizing > 100% Flood Control Storage: 11 projects

US Army Corps of Engineers

Now, the same pictures are on the left.

It may be hard to believe that encroaching on a flood pool could result in flooding during the middle of a drought.

This is exactly what happened in Texas during the Memorial Day floods of 2015 that occurred during a multi-year drought, and again around Memorial Day 2016. And we've seen some of the same in 2017 in California.

CLICK for map of precipitation in Texas region, May 2015.

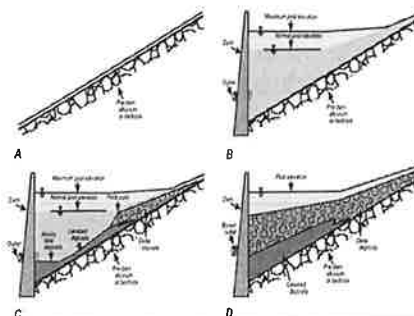
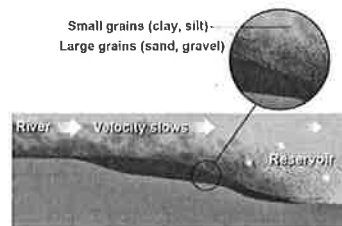
The 2015 event is shown here. Note that the precipitation map on the left shows up to 600% of normal rainfall (magenta). This is a tough way to end a drought.

51 reservoirs were in flood pool, and 11 of these were above the flood pool. Some of these reservoirs were only able to avoid more serious downstream flooding because they were lower than normal due to drought.

So this is a real IWRM issue we are facing now.

## RESERVOIR SEDIMENTATION

- Reservoir designs plan for sediment build up over time
- Sedimentation can reduce reservoir storage for flood control and water supply
- Location of the sediment deposits varies with
  - river flow
  - reservoir elevation
  - freeze-thaw
  - wildfire
- All factors impacted by climate change



The observed and projected changes in drought and precipitation not only pose challenges for water managers but also affect both the rate at which sediment is produced in a watershed and the ability of streams to transport this sediment and ultimately deliver it to reservoirs.

Watershed sediment yields are expected to increase with increases in rainfall intensity, especially after wildfire, and as more precipitation occurs as rainfall rather than snowmelt.

Changes in the amount of sediment eroded and transported from a watershed also result when land cover is altered (such as through forest conversion to farmland or by wildfire), and land use is changed (such as from rural to urban).

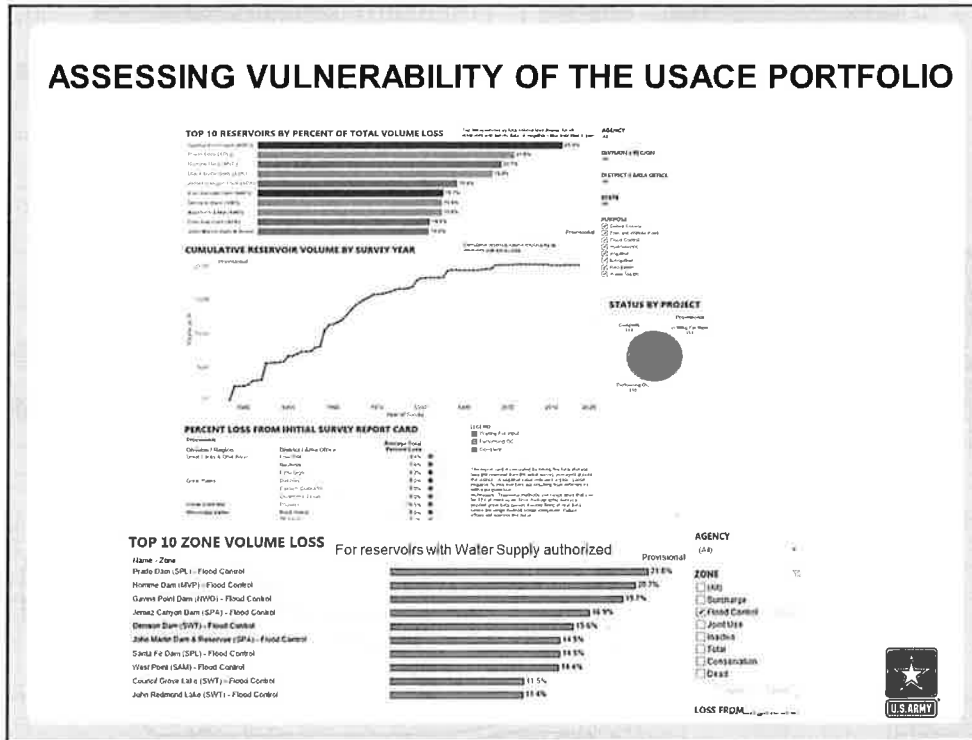
Reservoirs are designed to account for sedimentation.

Over time, as reservoir surface and river flows fluctuate, the sediment deposition can occur and migrate toward the dam.

The location of sediment deposition changes with river flow, reservoir elevation, freeze-thaw, and wildfire, all impacted by changing climate.

Thus, sedimentation impacts all of the reservoir storage zones and can potentially impact the function of the outlet works.

# ASSESSING VULNERABILITY OF THE USACE PORTFOLIO



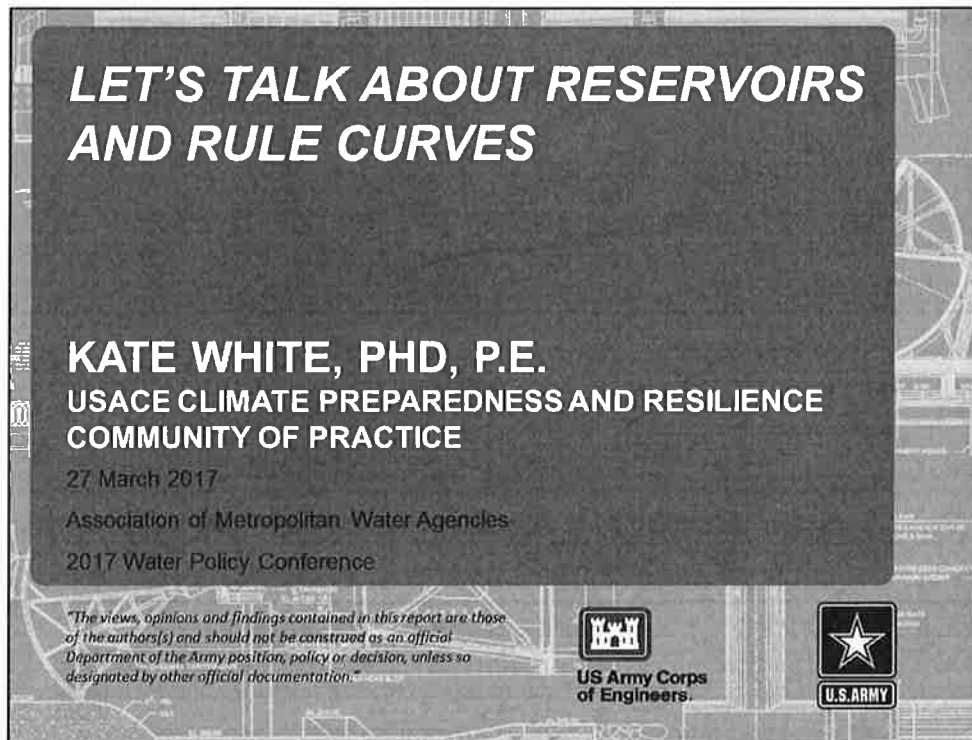
For the past several years, we have been compiling reservoir sediment information in a portal that Reclamation is also now using. This information allows us to identify reservoir reliability and performance vulnerabilities now and in the future, and supports development of strategy and prioritization for sediment management and other actions such as Drought Contingency Plan updates and reservoir sediment management.

For example, we can look at storage losses in reservoirs with water supply as an authorized purpose. Here, we see that most of the zone loss is in the flood control pool. In fact, with the data as we have in hand now, very little of the loss has occurred in the conservation pool. Of course, we are making efforts to collect better data.



Thanks for your attention. I'll be happy to answer any questions.

But I want to ask one too – did anyone learn anything new?



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