Approaches to Resiliency at TVA

Clayton Clem, Tennessee Valley Authority
VP Transmission Strategic Projects & Initiatives

Tennessee Valley Authority

- Created in 1933 by the TVA Act
- A federally-owned, self-financed corporation
- Mission: Provide navigation, flood control, electric power, and economic development in the Tennessee Valley region
- Largest public power system
- Service Area:
  - Parts of 7 states
  - 80,000 square miles
  - 9 million people
- Primarily a wholesaler of power serving distributors and large industries.

What We Manage

- 16,194 miles of lines
- 512 substations/switchyards
- 104,467 transmission structures on 237,528 right-of-way acres
- 1,293 individual interconnection & customer connection points
- 2,700-mile fiber network

to deliver

- 33,500 MW peak load
- 155 x109 kWh

Transmission Grid Resiliency

reliability *- the ability of the system and its components to withstand instability, uncontrolled events, and cascading failures, during normal operation and routine events**

resiliency *- the ability of the system and its components (i.e. both the equipment and human components) to minimize damage and improve recovery from non-routine disruptions, including high impact, low frequency (HILF) events, in a reasonable amount of time**

Resiliency is an essential element for grid owners and operators as responsible custodians of the public trust.

Key Elements are:

- Design Standards
- Operating Procedures
- Emergency Planning
- Emergency Inventory
- Restoration Activities

* From NATF

Transmission Grid Resiliency

16 Critical Infrastructure Sectors: all depend on electricity.

Our industry has changed

- Public expectations have changed.
- Excess transmission capacity is largely gone.
- We don’t have the same workforce.
- Challenges to resiliency today are much broader.

Natural or human events can cause much more severe damage in a densely developed modern infrastructure. Even if unlikely, risks must be considered.

Recent examples:

- Hurricane Sandy
- Fukushima
- Malware, ransomware (Iran, Ukraine, UK)

Transmission Grid Resiliency

Recent Legislative, Regulatory, Government Publications

- 2013 - New York Public Service Commission (PSC) Emergency Response Performance Measures scorecard.
- 2013 - The Oregon Resiliency Plan, Washington State Resiliency Plan
- 2013 - Maine Act to Secure the Safety of Electrical Power Transmission Line
- 2014 - NERC Reliability Leadership Summit (September 11, 2014) “Preparing for the Worst (Resiliency & Recovery)”
- 2014 - NATF & EPRI proposed a model for utilities to use in October 2014.
- 2015 - TVA utilizes NATF format for Grid Resiliency Story
- 2015 – National Electrical Safety Code Summit discusses resiliency
- 2015 - NIST, Community Resiliency Program
- 2016 - FAST Act
- 2016 - The National Defense Authorization Act (NDAA) for Fiscal Year 2017, H.R.4909
- 2016 – DOE, EPRI: Joint Electromagnetic Pulse Resilience Strategy
- 2016 – DHS: EMP Protection and Restoration Guidelines for Equipment and Facilities
- 2017 – DOE: Transforming The Nation's Electricity System: The Second Installment Of The Quadrennial Energy Review

TVA’s Resiliency Tool

TVA

Transmission & Power Supply

Transmission Grid Resiliency Review (TGRR)

	CYBER ATTACK	EARTHQUAKE	EMP	GAS-ELECTRIC INTERDEPENDENCY	GMD	MAJOR EQUIPMENT	PHYSICAL ATTACK	SEVERE FLOODING	SEVERE STORMS	SINGLE POINT FAILURE	WORKFORCE AND SUPPORT	COMMUNITY RESILIENCY
Assess (Design Basis)	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Prevent/Harden (Design Changes, Projects, etc.)	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Detect/Monitor	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Operating Guides	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Recover/Restore	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Emergency Checklist	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Drills	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Operational Integration	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴
References	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Subject Matter Experts	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴

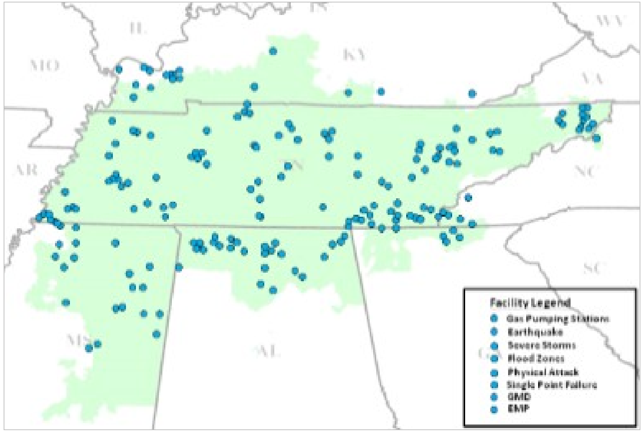
TVA and Transmission Links

TPS SharePoint | Emergency Preparedness | TPS Safety

(Links available while online with the TVA Network only)

- Includes operating guides, emergency checklists, drills, references and subject matter experts.
- Covers a wide range of risks including earthquake, gas electric interdependency, major equipment, severe flooding, severe storms and workforce support.
- Provides focus for $400M statewide improvements

- 12x12 interactive matrix
- Linked reference material for rapid access
- Reference for knowledge transfer



TVA

TVA's Expanded Planning

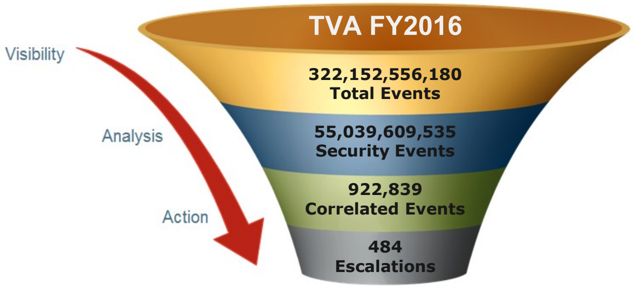
TVA transmission resiliency planning has transitioned to a much wider view of severe risks.

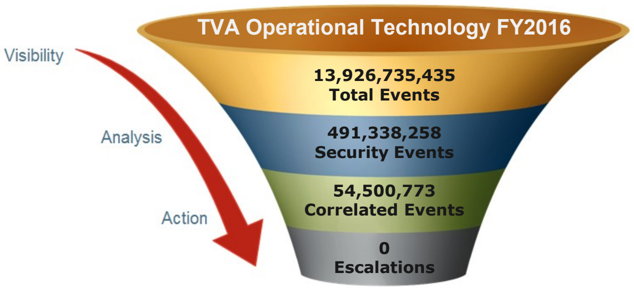
- Cyber Attack
- Earthquake
- EMP
- Gas-Electric Interdependency
- GMD
- Major Equipment
- Physical Attack
- Severe Flooding
- Severe Storms
- Single Point Failure
- Workforce and Support
- Community Resiliency
- Communications (Next Steps)

The risks cover a range from high to low probability.

Probability of man made events is unpredictable.

Cyber Attack





Problem:

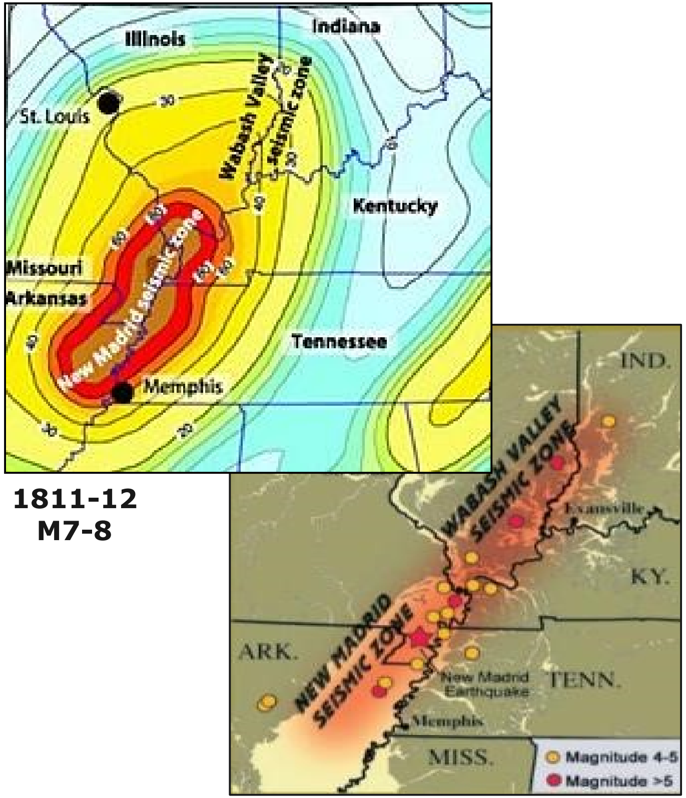
Potentially system-wide, unexpected loss of communication and control, possibility of equipment damage

Response:

- Defense in depth
- Procedures – NERC CIP, NIST/FISMA
- Continuous monitoring 24/7
- Security monitoring (internal / external, system integrity)
- Incident Response and Recovery plans / Drills
- Vulnerability Scans and Assessments
- Equipment reviews
- Audits, assessments & revised protocols
- Partner with federal, state and local law enforcement & key industry security groups such as E-ISAC

Reported attacks are escalating – energy sector is an obvious and strategic target

Earthquake – New Madrid Seismic Zone



1811-12
M7-8

Problem:

Potentially widespread, unexpected, coincident damage (water, transport, injuries), involves equipment with long replacement times.

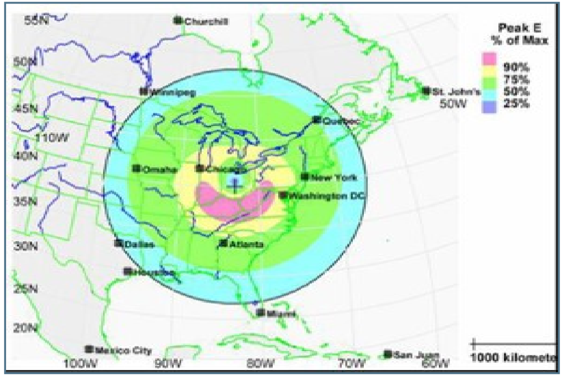
- USGS estimates 1811-1812 event has a 7-10% probability in 50 years
- M6 has a 25-40% probability in 50 years.

TVA Response:

- Tie-down large power transformers
- Structurally harden masonry switch houses to provide two 500-kV and one 161-kV paths back into Memphis / West TN area.
- Replace old equipment with seismically resistant.
- Revise procurement specifications to require seismically qualified equipment.
- Shake table tests on a 500-kV transformer bushing to determine resiliency and conductor slack for bus connection.

Earthquake – Hardening the Switch Houses (Weakley)

EMP and IEMI



The Problem:

A high altitude nuclear weapon interacts with the atmosphere and magnetic field to cause a very high electric field over a wide area.

The electric field has the potential to damage low voltage equipment and electronics.

Changing Environment:

New players with attack capabilities, evolving technology has increased vulnerability.

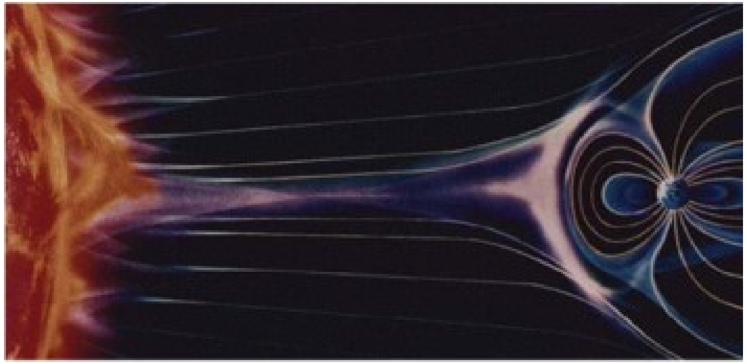
New interest – EIS Council, Sen. Franks (Critical Infrastructure Protection Act), TVC Secure Grid Initiative, State Health Commissioners.

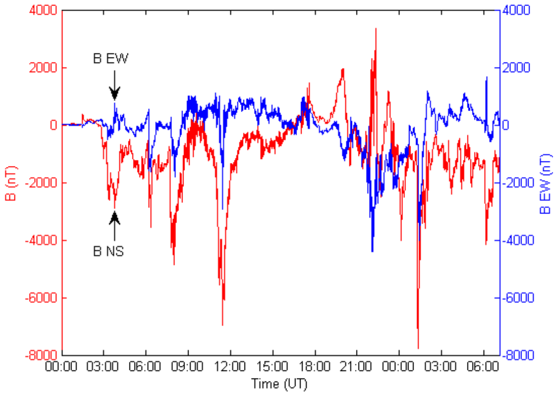
Possible Consequences:

All critical infrastructure that is dependent on electricity is at risk. Potentially very widespread, unexpected, coincident damage (water, transport, communications).

However there are many unknowns regarding the effects of EMP on existing infrastructure.

GMD





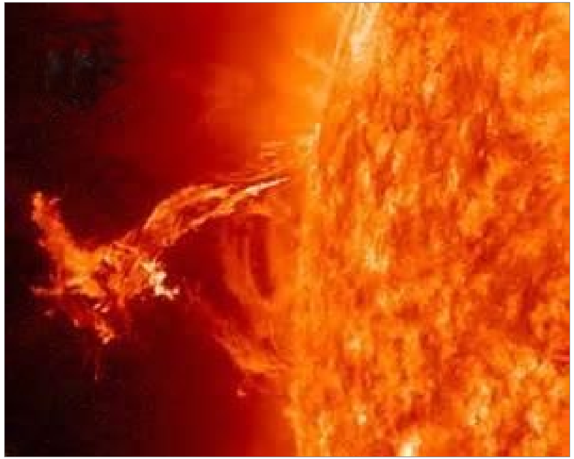
Problem:

- Potentially widespread injection of Geomagnetic Induced Current (near-dc) causing harmonics and overheating of transformers. There will be reasonable notice of impending storms. (new DSCOVR satellite)

TVA Response:

- Operating procedures to ensure operator awareness
- Replaced vulnerable relays on capacitor banks
- Network of 12 Sunburst detectors plus magnetometer
- Research blocking device design
- Assessment of 144 500-kV transformers for saturation and heating
- GIC system model and studies in advance of TPL-007
- Plan stepped operating response for extreme events

GMD – Planning for >1/100 Year Storm



Date	Sites > 10A	TVA Reading	Max NOAA K	Cause
05/27/17 – 05/28/17	4	Paradise (KY): -6.3A to 14.5A	K-7	CME
02/17/16	2	Paradise (KY): -6.9A to 7.2A	K-6	Coronal Hole
12/31/15 – 1/1/16	3	Montgomery (TN): -4.8A to 5.1A	K-6	CME
12/19/15 – 12/21/15	3	Widows Creek (AL): -8.2A to 4.3A	K-6	CME
10/7/15	4	Paradise (KY): -6.4A to 9.1A	K-7	Coronal Hole
8/15/15 – 8/16/15	4	Paradise (KY): -7.8A to 9.4A	K-7	CME
06/22/15 – 06/23/15	11	Paradise (KY): -15.6A to 16.2A	K-8	2 CME
3/17/15	9	Montgomery (TN): -13.5A to 14.6A	K-8	CME
3/1/15	5	Montgomery (TN): -6.5A to 4.3A	K-5	Coronal Hole
1/7/15	6	Paradise (KY) 5.5 - 16.7A	K-7	CME

Presently expect no problems for 1/100 storm

- Studies to date show only one location within benchmark, 3 more at extreme levels

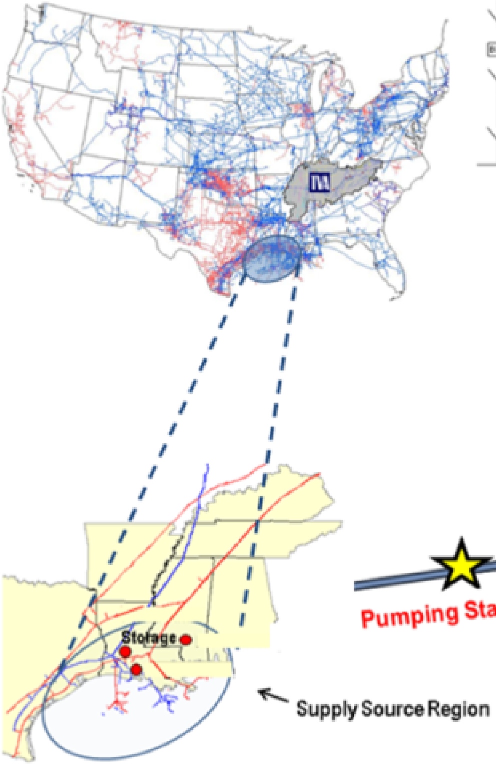
Current Issues

- FERC requirement for changes to TPL-007
- Validate system models from GIC and field measurements
- Implement magnetometer network to obtain storm field dynamic structure
- Implement real time displays for system monitoring

Future Schedule

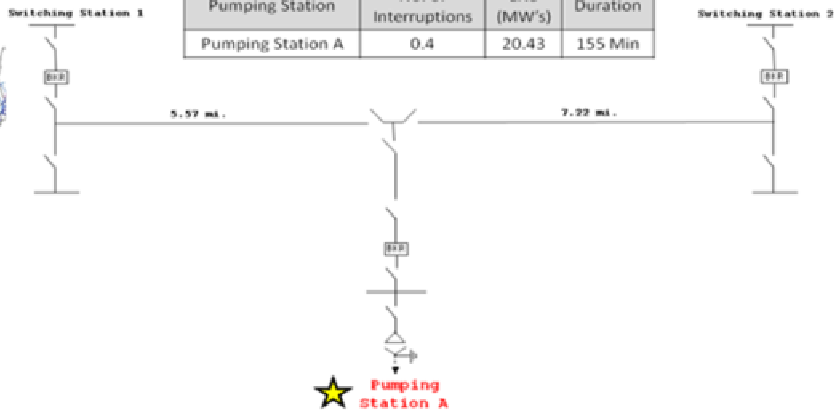
- Develop advanced procedures for operations
- Prepare for next storm cycle peak ~ 2025

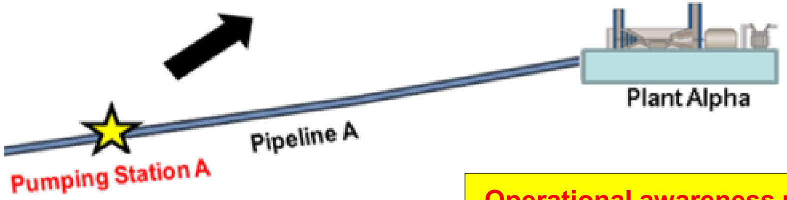
Gas-Electric Interdependency



Switching Station 1 – Switching Station 2 161-kV TL 5-year Average Reliability

Pumping Station	No. of Interruptions	LNS (MW's)	Duration
Pumping Station A	0.4	20.43	155 Min





Operational awareness used to prioritize restoration efforts

Major Equipment

Problem:

Large equipment is vulnerable to physical and electrical disturbances, difficult to relocate, requires a long time to repair and replace.

TVA Response:

- Appropriate seismic requirements specified for major equipment per IEEE 693 (ex. power transformers, circuit breakers, instrument transformers)
- Wind loading requirements and regional ice loading requirements for specific major equipment and interconnected bus work and insulators.
- Provide slack in jumper connections to transformer bushings for seismic movements

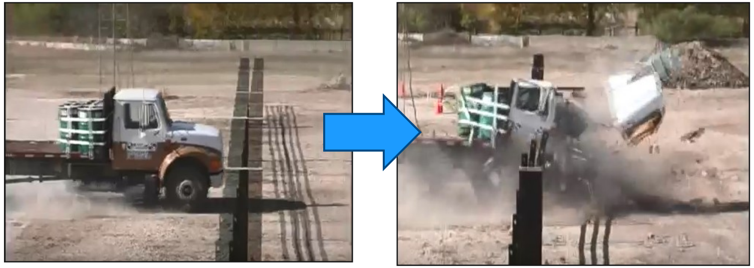
Major Equipment

Standardization enables a robust transformer spares program

- 2003 TVA did a fleet wide transformer assessment.
- Established a standardized replacement program with limited replacement designs
- Designs can be manufactured in multiple factories worldwide.
- Over 10 years transformer standardization
- Over 90 Alpha and Bravo Class standard transformers
- Used for replacement and all new stations
- Makes transformers across the fleet interchangeable
- Provides a significant number of system spares
- Makes our extensive spare inventory useable fleet-wide
- Studies add ability to exchange some dis-similar transformers as well.

Micafil RIP Bushing on Transformers
- Limits damage if the transformer blows up
- Better for taking on gunfire
- Does not launch or explode like Porcelain

Physical Attack



Problem:

Electric power grid facilities are widely dispersed and very difficult to protect against physical attacks. Damage to critical substations potentially could trigger cascading outages.

Response:

- Implemented plans for requirements of ES-ISAC Aurora advisory, NERC CIP-002 – CIP-011, CIP-014
- Physical & process barriers for detection, intrusion and tampering
- Card readers, alarm contacts, video monitoring, etc.
- Enhanced camera installation with analytics & 24x7 monitoring
- TVA Police & local law enforcement coordination
- Installed higher, anti-cut, anti-climb, anti-ram fencing

Physical Attack

CIP-014-2:

- Automation tools used to evaluate multiple methodologies to determine cascading scenarios.
- Each methodology simulated the total loss of a substation as a result of a physical attack in steady-state and dynamic analyses.
  - Three-phase faults at all voltage levels at a substation isolated remotely with normal clearing
  - Single-phase faults at all voltage levels at a substation isolated remotely with delayed clearing
- Instability & cascading criteria determined by internal analysis and industry benchmarking which align with NATF survey results.

Response:

- Implementing protection scheme modifications at all critical stations to remove potential for cascading

Flooding

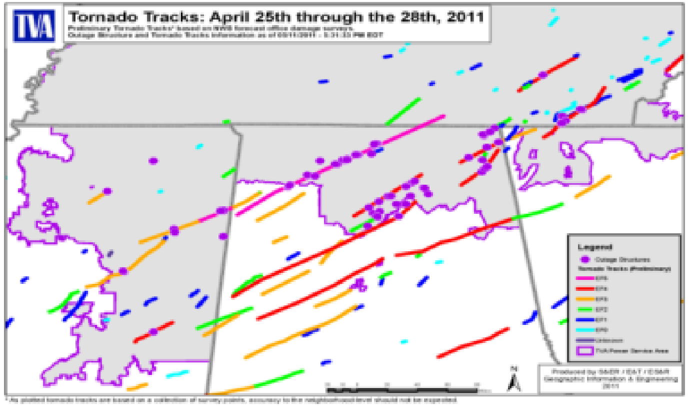
Problem:

- Extreme weather can cause flooding and threaten grid equipment. Example: 15 inches of rain in 2 days of May 2010 caused a river crest 25.5 feet above flood stage.

Response:

- Transmission assets reviewed using FEMA flood data as layers in TVA GIS map
- Multiple Flood Hazard scenarios were considered including
  - 1% annual chance (100 year flood)
  - Regulatory floodway
  - Special floodway
  - 0.2% annual chance (500 year flood)
  - Future conditions 1% annual chance
  - TVA's Zone A Probable Maximum Flood for the Tennessee River
- Relocate assets to areas that will not flood. In the example above, a 161-kV substation was relocated

Storms



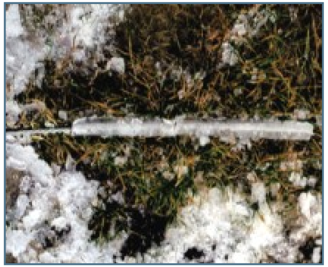
Problem:

- Extreme weather including tornadoes and ice storms can cause mechanical loads on substations and transmission structures to exceed design limits.

Response:

- Maintain and mobilize crews in advance, anticipate communication and support requirements (food, lodging) during restoration.
- Replace wood poles with steel for new construction and preventive maintenance, use robust alumoweld shield wire. Apply icing criteria to minimize faults when re-energizing.
- Developed steel inventory plan for restoration utilizing a limited number of standard TVA tower types to reduce inventory.
- Collaboration with the U.S. Army Cold Regions Research and Engineering Laboratory to create the Region 2 Ice Maps as basis for NESC 250D - Extreme Ice.

February 8-12, 1994 Ice Storm



Workforce/Support

Low probability high consequence events may overwhelm resource availability.

Problem:

The workforce required to respond safely, efficiently, and orderly to a major system interruption or natural disaster will come from various sources. The expertise and experience of internal resources, including safety professionals, will be called upon first to provide engineering, procurement, construction, and oversight services. After assessing and assigning internal resources, additional support may be required.

Response:

- Memorandum of understanding with labor
- Mutual aid and other agreements for support
- Assess and arrange for logistical needs (food, lodging, hygiene, security, traffic control, etc.)
- Fuel sustainability: gasoline, diesel, aviation and propane
- Heavy-haul agreements
- Material and transport
- Heavy equipment support

Community Resiliency

Critical Load Examples

16 Critical Infrastructure Sectors – all depend on electricity.

- Chemical
- Commercial facilities
- Communications
- Critical manufacturing
- Dams
- Defense industrial base
- Emergency services
- Energy
- Financial services
- Food & agriculture
- Government facilities
- Healthcare & public health
- Information technology
- Nuclear reactors, materials & waste
- Transportation systems
- Water & wastewater systems

TVA Response:

- Integrate resiliency planning with LPCs and communities
- Strengthen TVA, LPC, and community body alignment using drill-based scenarios

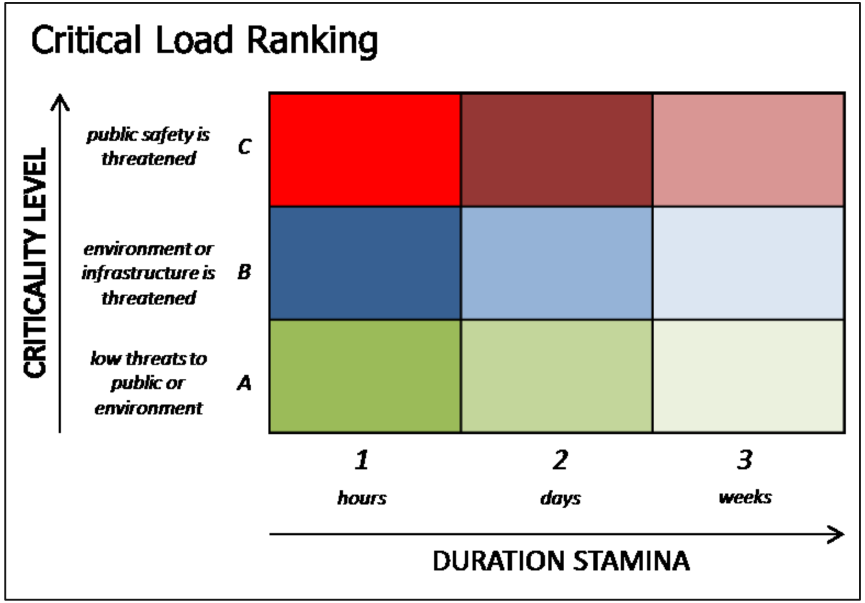
Enhancing community resiliency requires coordination of multiple preparedness and emergency plans

Critical Load Evaluation

- For the improbable blackout-type event, TVA desires to develop a prioritized ranking of load to restore first if the opportunity is available.
- The process will require information from LPCs about the critical loads and durations that can be withstood.
- Ranking consistency is important.

Information Requested:

- Critical Load:
  - Location
    - TVA Delivery Point & Voltage
  - Type
    - Motor Starting?
    - Continuous/Intermittent?
  - Amount (MW)
  - Ranking
    - C1, C2, C3
- Is Backup Generation Available?
  - If so, what is the duration?



Questions?

TVA