



waterscapes

HDR

A TECHNICAL PUBLICATION
BY HDR'S WATER GROUP

2015, No. 2
Resiliency



Resiliency

© iStockphoto.com/HDR

CONTENTS

02

Resiliency -
A Global Movement

04

Resiliency's Role
in Our Coastal Communities

08

Resiliency in
Fisheries Design

12

Seismic Considerations for
Water Distribution Resiliency
in California

17

Long Range Water Supply
Plan for the City of Dallas

2015, No. 2

Waterscapes is a technical publication produced and distributed by HDR.

Address changes and correspondence should be sent to the attention of:

waterscapes@hdrinc.com

TECHNICAL EDITOR

Matt Redington

WATERSCAPES EDITOR

Raffaella Geremia

Sara Nash

EDITING & DESIGN

Marketing Services

Creative Studio

hdrinc.com

© 2015 HDR, all rights reserved

For information on career opportunities at HDR, please visit: hdrinc.com/careers

We practice increased use of sustainable materials and reduction of material use.

Waterscapes is offset printed on Utopia Two Xtra Green 100# Dull text, which is FSC-certified paper manufactured with electricity in the form of renewable energy (wind, hydro, and biogas) and includes a minimum of 30% post-consumer recovered fiber.

(Cover) Hurricane Sandy off the southeastern United States, 12:00 PM (EST) October 28, 2012. Courtesy of LANCE MODIS Rapid Response Team at NASA GSFC.

REFLECTIONS ON HURRICANE KATRINA

Ten years ago this August 29, Hurricane Katrina came ashore as a Category 3 storm in Louisiana, impacting residents along the entire Gulf Coast. The damage to infrastructure was staggering. Levees breached and floodwalls toppled. Eighty percent of New Orleans was inundated by floodwaters. Gulfport and Biloxi, Mississippi, were devastated. Power lines were downed and electrical groundwork flooded across a multi-state region. According to the Federal Emergency Management Agency (FEMA), there were \$108 billion in estimated property damages, making it the most costly natural disaster in U.S. history. It was the human side of the tragedy, however, that was incredibly moving and continues to resonate with us today.



New Orleans, LA, September 3, 2005-Colorado Task Force 1 Hazardous Materials Technician Jeff Meyers carries an infant to safety. Photo by COTF1

and homes are lost. In the aftermath of Katrina, after the sheer magnitude registered, we were poignantly reminded that designing and building community flood protection is about much more than building infrastructure to meet criteria stated in a manual.

Since 2005, there have been other weather-related disruptions, or shocks, to our nation's communities. In 2008, there was flooding across much of Iowa. In Cedar Rapids alone, 10 square miles of urban area flooded, 18,000 residents displaced and 310 city facilities damaged. To the east, Superstorm Sandy slammed into the Mid-Atlantic in 2012, causing inundation of highly populated coastal areas in New York City and New Jersey.

Other shocks that have occurred, or are ongoing, are unrelated to community flood protection. For example, there is an evolving and ever-worsening drought crisis in the southwestern United States that threatens to change the way food is brought to our table and disrupt communities whose wells cannot provide any more water. Other shocks relate to the effects of climate change on species or wetland systems that are integral to our environment and shape the way we live.

Katrina is just one example of why the concept of community resilience is so important. This issue of *Waterscapes*, published 10 years after Katrina, is devoted to a broad view of resilience. The articles discuss how we are planning for potential future shocks or adaptively managing our systems to prepare for the future. The articles relate to constructed systems, community planning and environmental systems, and provide evidence of how people are deeply affected by our designs and planning decisions. We believe the principles of resiliency discussed in these articles are achievable, practical and essential for our communities. Resiliency will be a key ingredient of future infrastructure and our communities.

Matt Redington, PE
Civil Works Technical Advisor
Minneapolis, MN

Resiliency – A Global Movement

By Bob Beduhn, PE, ENV SP
Civil Works Director, Omaha, NE



© iStockphoto.com/HDR

The concept of community resiliency was borne out of the broad-reaching concerns regarding human-induced climate change and social consequences of natural disasters. The modern resiliency movement can trace its roots to December 1999, when the United Nations General Assembly adopted the International Strategy for Disaster Reduction and formed the United Nations Office for Disaster Risk Reduction (UNISDR) Secretariat to ensure its implementation.¹ UNISDR was formed to implement the “Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters.”²

At the center of the Hyogo Framework, there are three main goals:

- Integration of disaster risk reduction into sustainable development policies and planning
- Development and strengthening of institutions, mechanisms and capacities to build hazard resilience
- Systematic incorporation of risk reduction approaches in the implementation of emergency preparedness, response and recovery programs

In March 2015, the mandate of the UNISDR was updated by passage of the Sendai Framework for Disaster Risk Reduction 2015-2030.³ The Sendai Framework is built upon lessons learned from the Hyogo Framework. Lessons learned from the Hyogo Framework identified several social needs that rely on infrastructure resiliency to serve the community long-term. Most notably, the recognition that short-term community sustainability gains — in terms of reductions in poverty, improvements in public health, and reliability of food, energy, education systems, and jobs — can be set back by a lack of infrastructure resiliency when a disaster strikes. The underpinning of a stable society is a resilient infrastructure system.

A more recent international trend, in addition to the UNISDR, is the increasing interest of nongovernmental foundations, investment and insurance entities in promoting and supporting the resiliency movement. Private sector interest is driven by business metrics such as supply chain management, business continuity and an increasing concern in worker protections. These interest groups include, among others,

the Rockefeller Foundation’s 100 Resilient Cities initiative, the RISE Disaster Risk Sensitive Investments initiative, Global Infrastructure Basel (GIB) Foundation, and the U.S. Business Council for Sustainable Development. A brief summary of each organization’s mission and goals follows:

100 Resilient Cities (100RC) – This initiative is “dedicated to helping cities around the world become more resilient to the physical, social and economic challenges that are a growing part of the 21st century. 100RC supports the adoption and incorporation of a view of resilience that includes not just the shocks — earthquakes, fires, floods, etc. — but also the stresses that weaken the fabric of a city on a day to day or cyclical basis.”⁴

RISE Disaster Risk Sensitive Investments – “The RISE Initiative is an ambitious global response to a daunting global challenge, a new way of collaborating, to unlock the potential for public and private sector actors who are ready and willing to make a step forward and take leadership on disaster risk reduction.”⁵

Global Infrastructure Basel (GIB) Foundation – This organization is a “Swiss foundation based in Basel working to promote sustainable and resilient infrastructure through sustainable infrastructure design and financing on a global scale.”⁶

U.S. Business Council for Sustainable Development – The council is “an action oriented and member-led nonprofit business association that harnesses the power of collaborative projects, platforms and partnerships to develop, deploy and scale solutions to ecosystems, energy, materials and water challenges.”⁷

These organizations, among others, demonstrate the global nature of the resiliency movement. The movement crosses geopolitical boundaries through coordination at the United Nations to improve the lives of affected people, and it involves an international finance, business and insurance system that focuses on business continuity and reductions in catastrophic losses resulting from disasters.

A recent report by PricewaterhouseCoopers predicts global economic growth at around 3 percent annually.⁸ The report highlights that the global economy will double by 2037 and nearly triple by 2050.⁹ That growth will occur in combination with ongoing global urbanization, marked by an increase from 54 percent of people living in urban areas today to 66 percent living in urban areas by 2050. According to the United Nations, this combination of economic growth and increasing urbanization will likely mean that over 50 percent of the infrastructure needed to meet the global population in 2050 has not yet been designed.¹⁰

The world is looking at U.S. disasters such as Hurricane Katrina and Superstorm Sandy and realizing it must do better to compete in an increasingly global economy. Economic and investment decisions will be made based on a community’s or a country’s overall resiliency and sustainability ratings. The winners in the global economy will be those communities and countries that demonstrate an ability to be resilient, to prevent business disruptions, to maintain continuity of services in spite of shocks and to overcome chronic social stresses.

President Barack Obama has been particularly active in addressing resiliency concerns by issuing or re-issuing several executive orders on the topic. These include Executive Order 13514 (Federal Leadership in Environmental, Energy, and Economic Performance), Executive Order 13653 (Preparing the United States for the Impacts of Climate Change), Executive Order 13677

(Climate-Resilient International Development), and a re-issued Executive Order 11988 for public comment (Executive Order 13690, Establishing a Federal Flood Risk Management Standard).

At a federal level, these executive orders are driving a re-examination of our approach, potentially changing it from relying on design life to designing for future adaptation and climate resiliency. The static assumption of past shocks being a reasonable estimate for future conditions is no longer considered valid by many political leaders in the United States, if not the world. As evidence, the U.S. Conference of Mayors updated their Climate Protection Agreement in 2014 to include climate resilience as one of the needed responses to climate change.¹¹

Engineering and community leaders should be aware of several major resiliency activities spurred by international non-governmental organization, private sector and governmental activity. These include the Rockefeller-HUD Natural Disaster Resilience Competition, the National Institute of Standards and Technology (NIST) Community Resiliency Guidebook, and the American Society of Civil Engineers’ new Infrastructure Resilience Division. The major theme of these efforts is to increase the focus on critical infrastructure systems, specifically those that are considered lifeline systems for human health and safety during a shock event.

For example, the Rockefeller Foundation and U.S. Department of Housing and Urban Development’s (HUD) competition has allotted \$1 billion in awards to fund the implementation of innovative resiliency projects created by communities recently struck by natural disasters.¹² The hope is to creatively distribute the remaining Community Development Block Grant disaster recovery (CDBG-DR) funds remaining from the 2013 Disaster Relief Appropriations Act.

The NIST Community Resilience Planning Guide for Buildings and Infrastructure Systems reflects a growing trend to integrate social, economic and infrastructure systems into a resilience-based design.¹³ The approach goes beyond pure economics or loss of life design approaches and instead integrates those into a broader community sustainability context.

In addition, the American Society of Civil Engineers, in establishing its Infrastructure Resilience Division, has broken its efforts into five committees.¹⁴ These include:

- Civil Infrastructure and Lifeline Systems
- Disaster Response and Recovery
- Emerging Technology

- Risk and Resilience Measurements
- Social Science, Policy, Economics, Education and Decisions

The Infrastructure Resilience Division is a good start to broadening the discussion of resilient design. Relative to overall community resiliency and sustainability considerations, critical water, power, transportation, healthcare and communication systems are considered too important to fail. These systems form the backbone of a community wanting to survive a shock event. A resilient infrastructure backbone allows a community to live in a sustainable manner day to day, knowing its investments in sustainability are secure and will provide the support network needed to rebound quickly following a shock event.

There is much work to be done to find an economic model that will support revitalizing United States’ levee, flood control and water infrastructure that addresses this new design paradigm. No matter how high we build flood walls, or how much steel and concrete are placed, there is always the potential for a bigger event.

Considering community resilience to major shocks is a process that can lead to viewing infrastructure in a different light. Profound discoveries that identify cascading failures, fatal flaws and underlying weaknesses in a community’s infrastructure system can be converted into strengths through adaptive design. These infrastructure strengths will then be the foundation that propels a community forward into an uncertain future, with the necessary strength to take on the climate challenges that lie ahead.

¹UNISDR. (2015). “Our Mandate.” www.unisdr.org/who-we-are/mandate.

²UNISDR. (2015). “Hyogo Framework for Action (HFA).” www.unisdr.org/we/coordinate/hfa.

³United Nations. (2015). “UN World Conference on Disaster Risk Reduction: 2015 Sendai, Japan.” www.wcdr.org.

⁴Rockefeller Foundation. (2015). “100 Resilient Cities.” www.100resilientcities.org.

⁵UNISDR. (2015). “RISE Disaster Risk-Sensitive Investments.” www.preventionweb.net/rise/home.

⁶Global Infrastructure Basel. (2015). “What is Global Infrastructure Basel (GIB)?” www.gib-foundation.org.

⁷U.S. Business Council for Sustainable Development. (2015). “United States Business Council for Sustainable Development.” www.usbscd.org.

⁸PricewaterhouseCoopers. (2015, February). “The World in 2050: Will the shift in global economic power continue?” www.pwc.com/gx/en/issues/the-economy/assets/world-in-2050-february-2015.pdf.

⁹United Nations, Department of Economic and Social Affairs, Population Division. (2014). “World Urbanization Prospects: The 2014 Revision, Highlights.” <http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf>.

¹⁰See footnote 9.

¹¹United States Conference of Mayors. (2014). “The U.S. Mayors Climate Protection Agreement.” *82nd Annual U.S. Conference of Mayors Meeting* <http://usmayors.org/climateagreement/Final%20USCM%202014%20Mayors%20Climate%20Protection%20Agreement.pdf>.

¹²Rockefeller Foundation. (2015). “HUD Launches \$1 Billion National Disaster Resilience Competition.” www.rockefellerfoundation.org/about-us/news-media/hud-launches-1-billion-national/.

¹³National Institute of Standards and Technology. (2015). “Community Resilience Planning Guide.” www.nist.gov/el/building_materials/resilience/guide.cfm.

¹⁴American Society of Civil Engineers. (2014). “Infrastructure Resilience Division.” www.asce.org/infrastructure-resilience/infrastructure-resilience-division/.

For more information about this article, please contact Bob Beduhn, Bob.Beduhn@hdrinc.com

Resiliency's Role in Our Coastal Communities

By Betty Dehoney, CEP, PMP, ENV SP - Principal Environmental Planner, San Diego, CA
and Lynette Cardoch, PhD - Water Resource Management Director, Denver, CO



Aerial view of Fort Livingston, Louisiana

When we think about our coastlines, many images come to life. We conjure expressions of vibrant cities, healthy marshes, fishing vessels landing their catch, distinct cultural pockets and rich social customs. We gain many benefits from the coast. We obtain our foods from it. We work in it. We play in it. We live it. Our coastal wetlands, on which many of these benefits rely, face intense survival pressures. Climate change is one of the greatest natural challenges to our coastal wetlands and the economic and social fiber of our coastal communities. Manifestations, such as sea level rise, extreme temperature and precipitation events and increased storm intensities, pose unique challenges to the integrity of our wetlands. Yet the health of our coastal communities relies on the survival of our coastal wetlands. Therefore, how do we help our coastal wetlands systems stay, or become, resilient enough to face climate challenge?

WHAT'S AT RISK?

Coastal wetlands are among the most productive ecosystems on earth. Coastal wetlands provide significant economic, biological and recreational values. In 2010, 123.3 million people, or 39 percent of the nation's population, lived in counties bordering the coastal shoreline.¹

More than half of commercially harvested fish in the United States depend on estuaries and nearby coastal waters at some stage in their life cycle. Coastal habitats provide spawning grounds, nurseries, shelter and food for finfish, shellfish and other wildlife.²

Resilience is the capacity of individuals, communities and systems to survive, adapt and grow in the face of stress and shocks, and even transform when conditions require it. Building resilience is about making people, communities and systems better prepared to withstand catastrophic events — both natural and manmade — and able to bounce back more quickly and emerge stronger from these shocks and stresses.

- Rockefeller Foundation 2015

The nation's coastal resources are an important habitat for a variety of birds (85 percent of waterfowl and other migratory birds) that use the area for resting, feeding and breeding grounds.³

Nearly 45 percent of the nation's endangered and threatened species are dependent on coastal habitats. Wetlands provide beneficial uses such as filtering, storing and detoxifying residential, agricultural and urban wastes. They also buffer coastal areas against storm and wave

damage and help stabilize shorelines. Considering all of the beneficial uses, the economic value of our coastal resources is likely to be in the hundreds of billions of dollars, if not more.⁵

CLIMATE CHALLENGES FOR COASTAL WETLANDS

Sea Level Rise

Sea level rise is one of the most obvious manifestations of climate change in our coastal communities. In low-lying areas such as Florida, Louisiana and the Carolinas, residents already see evidence such as increased coastal flooding, higher tides and salt water intrusion. If conditions are conducive, over time coastal wetlands can migrate inland. The key questions associated with the ability of wetlands to be retained involve a combination of natural and human constraints:

- Is there substantial infrastructure investment in place that needs to be retained and protected?
- Are there steep slopes that will result in a conversion of coastal wetlands to deep water habitats?
- Is the land adjacent to the current coastline at a shallow slope that will allow the subtidal habitat to migrate landward while maintaining coastal productivity?

As shown in Figure 1, coastal resources are generally defined by upland, intertidal or subtidal zones depending upon exposure to tidal action. Uplands are generally not subjected to influence from tidal action, although there may be some salt spray. Except for very unusual conditions, the habitat is not wetland dependent.

The intertidal zone is the area that is exposed to the air at low tide and submerged at high tide. This area can include many different types of habitats, including steep rocky cliffs, sandy beaches or vast mudflats. Organisms in the intertidal zone are adapted to harsh extremes. Water can be high due to tides, rain or runoff, and this water can be very salty at one time but very fresh at another time.

Coastal mudflats in the intertidal zone support a myriad of resident and migratory waterfowl activities — both biologically and economically. According to the U.S. Fish and Wildlife Service, birders spent an estimated \$15 billion on their trips and \$26 billion on equipment in 2011; however, when including other factors such as employment and tax revenue, birders generated \$107 billion in total industry output, 666,000 jobs and \$13 billion in local, state and federal tax revenue.⁶ With the loss of these resources, substantial biological, social and economic effects would be felt.

The subtidal zone is the area below the low tide water line and is always covered by water. This area can include many different types of habitats, including soft and hard bottom, submerged aquatic vegetation beds and coral reefs.

As shown in scenario (c), major infrastructure investments (roads, ports, industry, housing, etc.) are often located in a coastal zone. In efforts to protect these investments and coastal populations, our protection measures (seawalls, levees, bulkheads, etc.) are sometimes at odds with the health of our coastal wetlands. As we continue to harden our coastlines, we take away the ability for coastal wetlands to potentially migrate upland to avoid being permanently submerged. This can result in a significant portion of the intertidal and shallow coastal line, which is so important to our marine life, to become lost.

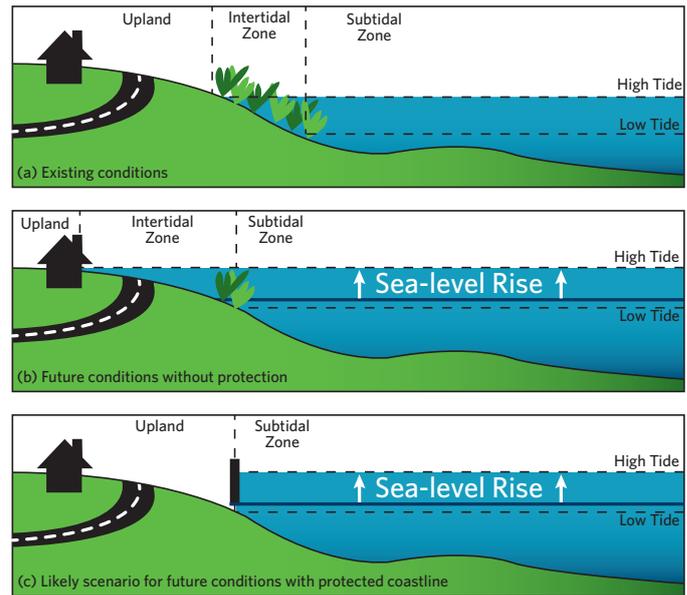
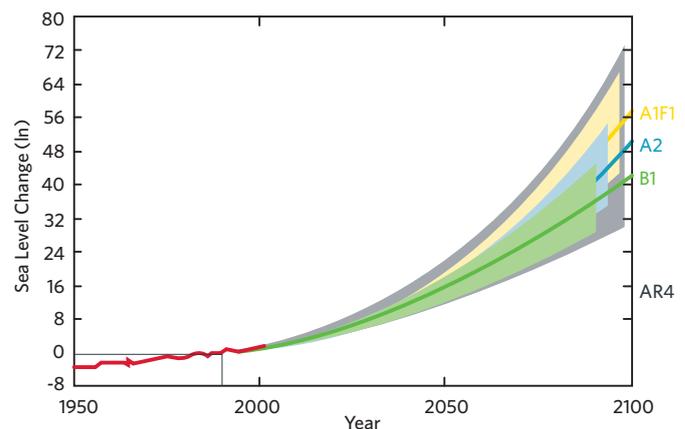


Figure 1: Tidal Action Defining Coastal Zones. Graphic adapted from Mello et al 2014

The effects of sea level rise vary by location depending on geologic considerations such as land subsidence (sinking) or uplift (rising). Modeling of various scenarios has identified potential global sea level changes of up to 6 feet by the year 2100.⁷

Louisiana is one of the United States' hot spots for sea level rise — with rates of relative sea level rise reaching up to 2 ½ inches a year (considering the effects of subsidence and increases in the water level). Other regions have typically seen increases in relative sea level rise of up to 2 inches.⁸ Wetland habitats in much of coastal Louisiana have suffered degradation and depletion attributable to altered hydrology, lack of nutrients and sediments from the absence



Projection of sea level rise from 1990 to 2100, based on three different emissions scenarios. Also shown, observations of annual global sea level rise over the past half century (red line), relative to 1990. Source: NRC 2010 as cited in EPA 2015

Louisiana is in the midst of a land loss crisis that has claimed nearly 1,900 square miles of land since the 1930s, and a scientific analysis confirmed that, without action, Louisiana could lose another 1,750 square miles in the next 50 years. Given the importance of south Louisiana's assets — waterways, natural resources, unique culture and wetlands — the effects of this additional land loss and increased risk of flooding would be catastrophic.

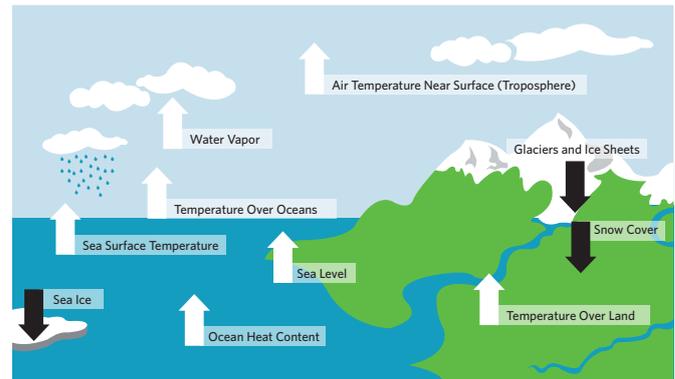
- Couvillion et al. 2011

of riverine influence and marsh subsidence. The degradation and loss of these coastal habitats has made existing marshes more vulnerable to Gulf of Mexico storms, both extreme and seasonal, resulting in accelerated degradation and further alteration of hydrology. The trend analysis from 1985 through 2010 for coastal Louisiana shows a wetland loss of over 16 square miles per year, a trend with critical implications for Louisiana's economy.⁹ Recent estimates indicate that approximately \$20 billion of existing coastal property will likely be below mean sea level by 2030. This amount increases to between \$33.1 and \$44.8 billion by 2050.¹⁰

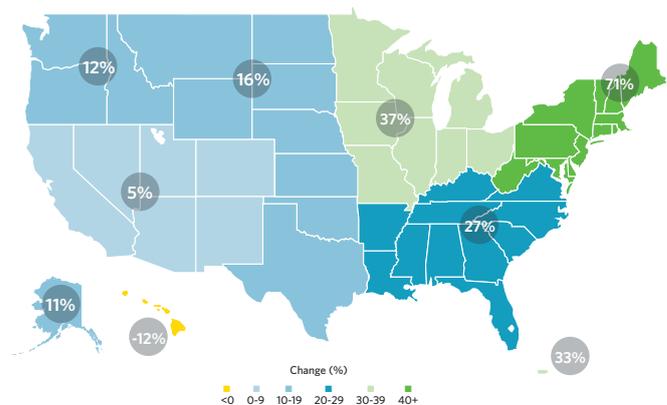
Temperature and Precipitation Changes

Average temperatures have risen across the contiguous 48 states since 1901, with an increased rate of warming over the past 30 years. Since the 1970s, unusually hot summer temperatures have become more common in the United States, and heat waves have become more frequent.¹¹ With increased temperatures and heat waves becoming more prevalent, precipitation patterns are changing.

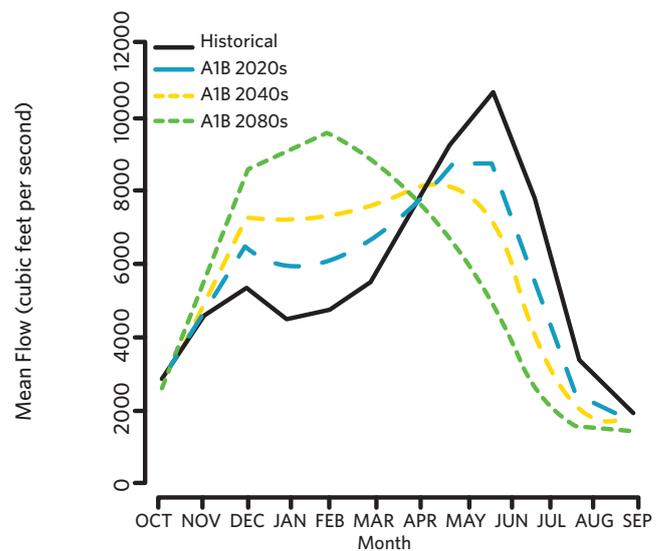
In recent years, a higher percentage of precipitation in the United States has come in the form of intense single-day events. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events (the heaviest 1 percent), particularly in the Northeast and Midwest.¹² The intensity of these storms can cause substantial damage to our coastlines. However, of greater concern is the changing amount and seasonality of precipitation, as well as the type of precipitation (rain or snow) that affects the physical and biological resources of the coastline. The interactions between changing water, air and soil temperatures and their effect on sea level rise are very complex. If amount and/or the seasonality of the rainfall changes, it will likely result in a shift in the wetland/riparian vegetation communities and the associated wildlife that rely upon that community. Wetland and riparian habitats are adapted to soil conditions that must be wet enough to support the vegetation needs. This relates directly to the amount of rainfall, how often it rains and the time of year it rains. Additionally, if warmer winters result in rainfall compared to snowmelt, streams and rivers feeding into coastal wetlands may change the inflow of freshwater and convert perennial streams into intermittent or even momentary drainages. Coastal wetlands may see a loss of certain species adapted to seasonal influx of freshwater because the salinity ranges may vary from acceptable levels.



Source: Melillo et al. 2014



Source: Melillo et al. 2014



Modeling has been conducted to assess the potential future river flow rates in the Yakima River basin for various climate modeling emission scenarios. Using the medium emissions scenario evaluated (designated as A1B), seasonal and peak flow changes were projected over three time periods: year 2020, 2040 and 2060. Mixed rain-snow watersheds, such as the Yakima River basin (an important agricultural area in eastern Washington), will see increased winter flows, earlier spring peak flows and decreased summer flows in a warming climate, causing widespread impacts. Natural surface water availability during the already dry late summer period is projected to decrease across most of the Northwest. Source: Melillo et al. 2014

REGULATORY CONCERNS

Climate change also tremendously complicates planning and permitting for development in our coastal areas. In January 2015, the President directed amendments to Executive Order 11988 of May 24, 1977 (Floodplain Management). This Executive Order requires executive departments and agencies to avoid, to the extent possible, the long- and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct or indirect support of floodplain development wherever there is a practicable alternative. With the amendment, the Executive Order was modified as follows: "Where possible, an agency shall use natural systems, ecosystem processes, and nature-based approaches when developing alternatives for consideration."¹³

For federally funded development in coastal areas, project planning will need to show that the project has considered incorporating more natural measures to avoid the long-term effects of climate change. This would likely include incorporating setback and buffers to accommodate sea level rise without jeopardizing infrastructure improvements. There will also be a necessity to respond to uncertainties associated with future conditions (for instance, will sea level rise 2 feet or 6 feet over the next 100 years) resulting in a need for these plans to be combined with an adaptive management program. The question becomes more explicit: How will a project be able to sustain itself and the surrounding environmental and cultural fabric in changing conditions? Fundamentally, the answer is resiliency — the ability of a total system (i.e., the built environment, the natural systems and the social fabric) to continue functioning in the face of disruptions.

If responding to uncertainties associated with the magnitude of sea level rise, intensity of storm events and precipitation is not challenging enough, permitting projects that require a Section 404 permit is likely to become more complicated. The U.S. Army Corps of Engineers (USACE) regulates discharge of dredged or fill material into navigable waters under Section 404 of the Clean Water Act. Impacts to wetlands and navigable water (Section 10 of the Rivers and Harbors Act and Section 404) require compensatory mitigation for unavoidable impacts. It may become more complicated for developers to determine the appropriateness of a proposed wetland mitigation plan when factoring in the uncertainties of climate change (habitat conversion due to temperature changes, sea level rise, etc.). USACE policies require that the site selection and site protection for mitigation sites provide for long-term viability of the wetlands mitigation.¹⁴ With long-term climate uncertainties, regulatory agencies could require long-term monitoring and adaptive management programs for mitigation sites.

INCORPORATING RESILIENCY INTO COASTAL PLANNING

Development has historically been most concentrated along coastlines and major waterways. The availability of local food and the ability to efficiently transport goods over waterways has allowed coastal populations to flourish. The concentration of people in coastal areas has been supported through massive investments in infrastructure. These development patterns occurred without recognition that our environment is changing. We are now faced with the challenge of maintaining the economic benefits, social values (recreation) and biological productivity and diversity of our coastal resources — this is going to require a changed paradigm in how we approach planning in and around our coastlines.

One of the most ambitious examples of responding to the loss of coastal wetlands is a program that Louisiana is evaluating. To protect its coastline, Louisiana is proposing a program to build land by diverting sediment-laden Mississippi River flows into basins.

These sediment diversions would build land through the ongoing contribution of sediments and nutrients and would stimulate marsh growth. Use of diversions would be a relatively slow process, but sediment transported through natural flow conveyance would be more sustainable over a long period of time. Land built using dredged materials subsides over time and requires future replenishing efforts. Additionally, sediment deficiency and the absence of fresh-water and nutrient inputs affect the marsh environment's ability to sustain itself.¹⁵ Fresh water from diversions and associated sediment load has been found to enhance the retention of marsh habitat.

The future holds a substantial amount of uncertainty related to the magnitude of climate change. Planning for increases in sea level, changes in precipitation patterns and rising temperatures will require using the best available science to avoid and minimize the effects of climate change. It will also necessitate incorporating backup plans (i.e., resiliency) to be able to adapt to climate change without causing a significant disruption to society's needs. Overall, a stronger emphasis on planning with an adaptive management plan to respond to the overall uncertainty of the change will be the most effective way to balance the economic, biologic and social needs of the community.

¹³National Oceanic and Atmospheric Administration (NOAA) National Ocean Service. (2014, February). "What percentage of the American population lives near the coast?" <http://oceanservice.noaa.gov/facts/population.html>.

¹⁴NOAA. (2015). "Status and Trends of Coastal Wetlands." <http://www.habitat.noaa.gov/protection/wetlands/>.

¹⁵See footnote 2.

¹⁶See footnote 2.

¹⁷Carver, E. (2013). *Birding in the United States: A Demographic and Economic Analysis: Addendum to the 2011 National Survey of Fishing, Hunting, and Wildlife-associated Recreation*. U.S. Fish and Wildlife Service, Division of Economics.

¹⁸See footnote 5.

¹⁹U.S. Environmental Protection Agency. (2015) "Future Climate Change." <http://www.epa.gov/climatechange/science/future.html>.

²⁰See footnote 7.

²¹Couvillion, B. R., Barras, J. A., Steyer, G. D., Sleavin, W., Fischer, M., Beck, H., Trahan, N., Griffin, B., & Heckman, D. (2011). *Land Area Change in Coastal Louisiana from 1932 to 2010*. U.S. Department of the Interior, U.S. Geological Survey. http://pubs.usgs.gov/sim/3164/downloads/SIM3164_Pamphlet.pdf.

²²Kinniburgh, F., Simonton, M.G., & Allouch, C. (2015). *Come Heat and High Water: Climate Risk in the Southeastern United States Risky Business Project*. <http://riskybusiness.org/uploads/files/Climate-Risk-in-Southeast-and-Texas.pdf>.

²³Mellillo, J. M., Richmond, T. C., & Yohe, G. W. (2014). Climate Change Impacts in the United States: The Third National Climate Assessment. US Global Change Research Program, 841 pp. DOI: 10.7930/10231W12. *Online at: nca2014.globalchange.gov*.

²⁴See footnote 11.

²⁵The White House (2015, January 30). "Executive Order – Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input." <https://www.whitehouse.gov/the-press-office/2015/01/30/executive-order-establishing-federal-flood-risk-management-standard-and->

²⁶33 United States Code 401 et seq., 33 United States Code 1344, and Public Law 108-136.

²⁷U.S. Army Corps of Engineers and Coastal Protection and Restoration Authority of Louisiana. (2004). Louisiana Coastal Area (LCA), Louisiana Ecosystem Restoration Study, Volume 2, Programmatic Environmental Impact Statement.

(d) Site selection.

(1) The compensatory mitigation project site must be ecologically suitable for providing the desired aquatic resource functions. In determining the ecological suitability of the compensatory mitigation project site, the district engineer must consider, to the extent practicable, the following factors:

- (i) Hydrological conditions, soil characteristics, and other physical and chemical characteristics;
- (ii) Watershed-scale features, such as aquatic habitat diversity, habitat connectivity, and other landscape scale functions;
- (iii) The size and location of the compensatory mitigation site relative to hydrologic sources (including the availability of water rights) and other ecological features;
- (iv) Compatibility with adjacent land uses and watershed management plans;
- (v) Reasonably foreseeable effects the compensatory mitigation project will have on ecologically important aquatic or terrestrial resources (e.g., shallow sub-tidal habitat, mature forests), cultural sites, or habitat for federally- or state-listed threatened and endangered species; and
- (vi) Other relevant factors including, but not limited to, development trends, anticipated land use changes, habitat status and trends, the relative locations.

(a) Site protection.

(1) The aquatic habitats, riparian areas, buffers, and uplands that comprise the overall compensatory mitigation project must be provided long-term protection through real estate instruments or other available mechanisms, as appropriate. Long-term protection may be provided through real estate instruments such as conservation easements held by entities such as federal, tribal, state, or local resource agencies, non-profit conservation organizations, or private land managers; the transfer of title to such entities; or by restrictive covenants.

Sources Cited in Graphics: Rockefeller Foundation. (2015). "Resilience." www.rockefellerfoundation.org/our-work/topics/resilience/

For more information about this article, please contact Betty Dehoney, Betty.Dehoney@hdrinc.com, or Lynette Cardoch, Lynette.Cardoch@hdrinc.com

Resiliency in Fisheries Design

By Ken Ferjancic

Fisheries Director, Santa Fe, NM



Recirculating Aquaculture System (RAS) at Peter W. Pfeiffer Fish Hatchery, Kentucky Department of Fish and Wildlife Resources, Frankfort, Kentucky

Fish can swim away from problems and have survived natural disasters for 400 million years. Do we really think we can add resiliency to fish and their environment?

Consider this current scenario. Idaho is home to Redfish Lake which has supported a sockeye salmon run for centuries. These juvenile fish (smolts) travel 900 miles from Redfish Lake, their natal grounds, to the Pacific Ocean only to return several years later as adults to spawn and create the next generation. Beneficial dams created in the Columbia River watershed in the last 60 years have had a secondary impact on the ability of Redfish Lake sockeye to return. Only 16 adult fish returned during the entire decade of the 1990s, creating one of the region's most endangered salmon stocks.¹

The National Oceanic and Atmospheric Administration (NOAA) Fisheries Service and Bonneville Power Administration collaborated to develop captive broodstock technology to aid in the recovery of this Endangered Species Act (ESA) stock. The hatchery, located in Kitsap County,

Washington, was designed specifically for this program. In 2010, captive broodstock reared in Washington and released into Redfish Lake resulted in over 1,800 adult sockeye returning to Redfish Lake to spawn.² Extirpation (the localized extinction of a species) was averted.

This summer the Northwest United States has experienced drought conditions that have created low flows and record high temperatures. High water temperatures (74 degrees Fahrenheit) experienced above Lower Granite Dam produced another lethal shock to this delicate system. A record number of Redfish Lake sockeye (over 4,000) passed Bonneville Dam (the first dam) as of August 6, 2015. Less than 386 sockeye survived to Lower Granite Dam (the eighth dam). It is feared that very few (two fish to date) will make it back to Redfish Lake.³

This is where resiliency through the captive broodstock program will kick in and protect the population. NOAA Fisheries Service is planning to spawn 600,000 eggs from its facility along with an equal number of eggs

from an additional program. This technology transfer is possible through the Idaho Department of Fish and Game. It is expected that these eggs will create almost a million juvenile fish to be planted in the lake. These smolts are then expected to propagate the population, since the current populace is experiencing a major shock with this year's extreme weather variations.

Resiliency in fisheries design focuses on aquatic species and their environment. HDR's fisheries professionals exercise ingenuity to design tools that provide resiliency for these aquatic species and their environment. We are continually challenged to address natural and manmade impacts to the environment and develop solutions such as conservation facilities, refugia and opening passages to unused habitat in order to help make fish populations more resilient. Even traditional facilities are being modernized with innovative techniques in order to be more effective at providing solutions that allow fish to survive and reproduce, and degraded environments are being rectified.

While resiliency issues have many dimensions, HDR is actively working on tangible solutions with our clients to address species resiliency and human infrastructure that can support that resiliency. Doing more with less water, enhancing the viability of a threatened species, making our supporting facilities more efficient and sustainable, and providing access to and protecting existing habitat are all valuable actions.

MORE FISH WITH LESS WATER

Augmentation, restoration, conservation and food production drive the increased need for fish of all types. Yet, as we've already discussed, fish need our help to keep numbers high. So, how does a community maintain a fish hatchery asset as a viable option? One solution is to reduce the vulnerability of a hatchery's resource inputs (i.e., make the facility more resilient).

Over 80 percent of the hatchery facilities that we and our clients currently have in planning or design phases involve the use of Recirculating Aquaculture Systems, commonly referred to as RAS. A RAS unit can have various treatment options depending upon the desired outcome. Typical components of RAS may include a solids collector, microscreen drum filter, foam fractionation, biofiltration (such as a moving bed bioreactor or fluidized sand bed), gas stabilization, oxygenation (in some cases for super saturation) and sterilization (ozone and/or ultraviolet).

Although the RAS approach has been researched for 35 years, the concept is seeing a strong resurgence due to improved technologies, increased efficiencies and the **acute shortage and quality of suitable water supplies**. These systems can typically reduce water consumption by 90 percent and increase a facility's resiliency in the face of a water shortage. In some applications, these systems have reduced water consumption as much as 98 percent. In addition to the flexibility of operating with reduced water requirements, this technology results in the ability to control water temperatures, use limited high quality groundwater and spring water supplies, reduce discharge to the environment, and increase the ability to control certain water quality parameters. Facilities we are currently planning, designing and/or constructing that involve RAS include:

- Wells Hatchery Modernization — Douglas County Public Utility District
 - Chinook Salmon, Coho Salmon, Steelhead, Sturgeon, Rainbow Trout and Cutthroat



© iStockphoto.com/HDR

The lamprey is considered a parasitic species of fish

- Louisiana Marine Fish Hatchery — Louisiana Department of Wildlife and Fisheries
 - Red Drum, Spotted Seatrout and Southern Flounder
- Native Salmonid Conservation Facility — Seattle City Light
 - Westslope Cutthroat and Bull Trout
- San Joaquin Conservation Hatchery — California Department of Fish and Wildlife
 - Chinook Salmon
- Quinnebaug Fish Hatchery — Connecticut Department of Energy and Environmental Protection
 - Rainbow and Brown Trout
- Pfeifer State Fish Hatchery — Kentucky Game and Fish
 - Walleye and Catfish

RAS units can provide enormous benefits to the success of fisheries. These units create optimal rearing environments with reduced water supply needs and can also operate under conditions of compromised water quality. With so much potential, we have been approached by two companies that are considering construction of large indoor fisheries with RAS units, hundreds of miles from the ocean. These facilities could be used to raise saltwater fish such as sea bass in an entirely enclosed building with nearly 100 percent recirculation of water and zero percent offsite discharge.

A STORY ABOUT THE HUMAN COMMUNITY ENHANCING AN ENDANGERED SPECIES' RESILIENCY

While the lamprey is considered a parasitic species of fish, restoration of this threatened population will better position the species for survival in the future and restore balance to a fish ecosystem. Dave Ward, HDR's Fisheries Science Practice Leader, is working with the Yakama Nation, Umatilla Indian Reservation and the Columbia River Inter-

Tribal Fish Commission to prepare a Lamprey Master Plan for Supplementation, Aquaculture, Restoration and Research. This plan will help the region conduct research, restore lampreys where they have been extirpated in the Columbia River watershed and support traditions of Tribes for which this is a food source. You grimace? Remember that the French in Bordeaux, consider this a delicacy only to be eaten with the finest aged wine! These ancient fish, which have survived for 350 million years, are in dire straits with counts as low as 1,408 at Wells Dam in 2003 and increase rates capping at 35 new fish per year since 2007.⁴ This plan will provide resiliency to lamprey while accommodating human harnessing of energy in one of the largest watersheds in the United States. Restoration facilities, research and expansion to available habitat provide resiliency for this species to recover and create a sustainable population.

SUSTAINING OLDER FACILITIES

The Quinsam River Hatchery located on Vancouver Island, British Columbia, Canada, has been in operation by the Department of Fisheries and Oceans (DFO) for over 40 years. We were selected as the design firm for the facility modernization and provided major upgrades to extend the facility's useful life. During the course of the modification design process, DFO inquired about the feasibility of generating power from its water source without impacting salmon hatchery operations.

We conducted an analysis which demonstrated that by incorporating low head gas balancing techniques, there was a net head of 59 feet at 24 cubic feet per second available for power generation. Collaborating with HDR's Hydropower Practice, our client was able to design, construct and commission a



Quinsam River Hatchery located on Vancouver Island, British Columbia, Canada

micro-hydro turbine generator at Quinsam River Hatchery. The micro-hydro unit was installed at the base of the head tank feeding the hatchery. The system has been certified by BC Hydro and now provides 268,000 kilowatt-hours (kWh) of the 480,000 kWh annually consumed by the facility.

Less reliance on conventional power and creating additional operating dollars from power bill savings helped justify the facility's future operation, which contributes to the salmon's success. Favorable economics, a willing client and a combined pool of HDR talent resulted in a successful demonstration of how we can work together to use innovation and operational changes to make older hatcheries more cost effective in meeting our goals to help maintain the resiliency of fish stocks.

A WIN-WIN ARRANGEMENT

As part of a settlement agreement with the Bureau of Reclamation, more water will be released from the Friant Dam on the San Joaquin River in California in order to restore salmon populations downstream.

We were retained by the California Department of Fish and Wildlife (CDFW) to design a Salmon Conservation and Research Facility that would hold a captive broodstock and produce a spring run of Chinook salmon smolts, using conservation rearing techniques, for release into the once again flowing river.

Locally adapted stocks of Chinook salmon from adjacent downstream tributaries will be collected and used to create a new Chinook gene pool for reintroduction into the main stem of the San Joaquin. Water from the reservoir above Friant Dam will be used to supply this new hatchery. The facility is an important tool in creating and enhancing species resiliency, through a captive broodstock program, for the reintroduction of this listed fish. Nearing 100 percent final design completion, the facility will be a reality soon. **But, a resiliency challenge has emerged that threatens the outcome.**

California is experiencing a severe drought that is causing lower river flows and a rise in surface water temperatures. Above the supply reservoir, this situation is producing water temperatures that are approaching lethal levels for the incubation of the Chinook salmon eggs. After preliminary design was complete and to address this issue, our Fisheries Design Center (FDC) team designed chillers with a partial recirculation system to maintain adequate incubation and early rearing temperatures. Concurrently, CDFW was seeing similar temperature impacts to water supplies at its other hatchery facilities throughout the state. Just before chillers and other equipment were purchased, emergency measures were put into place to incorporate chilling with partial recirculation. Through this effort, we have been further retained

to support the State of California in evaluating equipment vendors and turnkey designs to add this resiliency feature to other facilities.

This story is not over. Restoring a run of salmon and reducing hatchery water temperatures below lethal limits addresses some of California's immediate problems. There are many more challenges in the queue that will need solutions to accommodate our ever-changing environment. For example, providing salmon access to more suitable habitat above future impassable barriers will allow the species to be more resilient in dealing with shocks to the system.

ACCESS TO MORE HABITAT

The life of a fish in U.S. waters is a challenge. It is especially so when access has been limited by road crossings, dams and other obstacles that prevent them from swimming to the other side of their "house." Over the last decade, we have been asked to make streams and rivers more resilient by creating passage structures that provide access to habitat with improved environmental conditions such as cooler water temperatures and high-quality water for all life stages. These projects stretch from the East Coast through the Central Region and to the West Coast, including Alaska.

Our clients are responsible for implementing projects worth \$50 million (for instance, fish collection systems designed to move

thousands of juvenile, out-migrating salmon a day) to \$50,000 (for instance, fish ladders designed to move potentially 10 endangered steelhead trout a year). In each case, we are safely transporting fish around high dams and opening up miles of critical habitat. This allows fish populations to bounce back, create resiliency within the environment and adapt to further urbanization and climate change shocks.

PROTECTING EXISTING HABITAT

Withdrawal and discharge of cooling water from power plants and manufacturing facilities can alter the habitat of fish and the aquatic environment. It is estimated that about 1,065 existing facilities use over 2 million gallons of water per day for cooling purposes.⁵ These potential impacts have caused the Environmental Protection Agency (EPA) to develop strict guidelines for these facilities under Section 316 of the Clean Water Act.

Our team has some of the top leaders within the U.S. for modeling the intake and discharge characteristics of these facilities. These modeling efforts develop solutions for operational and design improvements to

cooling water discharge, aimed at minimizing impacts to fish and their habitat. These improvements keep the aquatic environment more resilient by reducing the magnitude of thermal shocks to the system.

CLOSING THOUGHTS

Critical fish species such as lamprey and salmon are facing rapid changes in their environments. Manmade modifications, such as dams, have compromised their ability to survive. Environmental changes like climate change, land use modifications, river water use or dam operations are, in some cases, increasing water temperatures to a level that can be lethal to fish.

Our goal, as HDR fisheries professionals, is to assist clients with keeping fish sufficiently numerous, healthy and diverse, in such a way that populations can thrive in spite of pressures or other system shocks. This can be done with enhancements to waterbodies such as adding fish ladders, refugia or openings. This can also be done by implementing new breeding programs or reviving the effectiveness or financial viability of older hatcheries.

A healthy and diverse ecosystem is resilient. Some of these species have survived hundreds of thousands of years of change but are now struggling to cope with human and environmentally induced changes. Through smart science and design practices, our Fisheries Practice is helping clients restore fish populations through creation of new facilities or restoration of old fisheries. Maintaining healthy stocks through fisheries supplementation helps provide critical support for species that are struggling with change. This can also provide time necessary for populations to adapt to new environmental conditions.

¹Columbia Basin Research. (2015). "DART Adult Passage Daily Counts for All Species." http://www.cbr.washington.edu/dart/query/adult_daily

²See footnote 1.

³See footnote 1.

⁴Fish Passage Center. (2015). "Lamprey Annual Adult Passage at: Wells Dam." http://www.fpc.org/adultsalmon/adultqueries/Adult_Annual_Totals_Query_form.html

⁵Ortiz, J.Q. (2014). "EPA Finalizes Standards to Protect Fish, Aquatic Life from Cooling Water Intakes." United States Environmental Protection Agency.

For more information about this article, please contact Ken Ferjancic, Ken.Ferjancic@hdrinc.com



California Department of Fish and Wildlife (CDFW) Salmon Conservation and Research Facility

Seismic Considerations for Water Distribution Resiliency in California

By Mark Stanley, PE, GE, D.GE

Geotechnical Senior Technical Advisor, Folsom, CA



The California Aqueduct system was developed in the 1960s to store water and distribute it to 29 urban and agricultural water suppliers in Northern, Central and Southern California

Water and the apparent ease in which it is conveyed is the foundation of California's urban communities, and water distribution systems are essential lifelines for their survival. These systems are vitally important to respond and recover from significant natural disasters including wildfires and earthquakes. California ratepayers have approved significant investment in the last decade to improve urban water systems' seismic survivability, primarily focusing on water storage and conveyance system vulnerabilities. In 2014, results from new seismic hazard forecasting tools were released which estimate that California is at greater risk than previously thought for large seismic events, specifically in Southern California. Concurrently, the cities of San Francisco, Los Angeles, Oakland and Berkeley have joined the 100 Resilient Cities program, an international movement to make urban communities more resilient. Urban resiliency is defined by this program as "the capacity of individuals, communities, institutions, businesses and systems within a city to survive, adapt and grow no matter what kinds of chronic stresses and acute shocks they experience."¹ Large-magnitude seismic events such as the 2004 Java (Indonesia) and 2011 Tohoku (Japan) earthquakes were acute shocks to urban communities with devastating impacts. California is now investigating potential impacts it may suffer as a result of a large seismic event.

CALIFORNIA'S WATER SYSTEM

In the last century, a network of reservoirs, canals and aqueducts has been developed by federal, state and local agencies to supply

potable water to the growing metropolitan communities extending from the San Francisco Bay Area to San Diego. As the communities grew, so did the network of distribution systems.

As shown in Figure 1, these communities receive water through a system of canals and aqueducts that bring water from storage reservoirs located in the Sierra Nevada Mountains or from the Colorado River in the eastern and northern part of the state. These conveyances cross a number of known active faults including the San Andreas, Calaveras and Hayward Faults as well as a significant number of parallel faults. Water is also conveyed through an aqueduct that crosses the seismically vulnerable Sacramento-San Joaquin Delta, founded on a deposit of soft, compressible organic and potentially



Figure 1. California's Water Distribution Systems. Source: Lauder 2014

liquefiable loose and cohesion-less granular soils. These conveyance systems are at significant risk for disruption due to fault movement and seismically-induced ground failures, including ground settlement, lateral slope instability and liquefaction, and flow failures.

The growth of California's urban communities has also put the growing areas themselves at significant risk. For example, the cities of Northridge and Hollywood were areas developed alongside previously unknown faults. Also, portions of the Marina District in San Francisco, which experienced damage during the 1989 Loma Prieta earthquake, were developed on reclaimed land. Land reclamation activities can expand development onto areas with deep, soft and compressible soils or landfill the area by placing loose fills with high liquefaction potential; either activity can amplify seismic ground motions.

NEW UNDERSTANDING OF SEISMIC HAZARDS

In 1971, the San Fernando earthquake registered 6.6 on the Richter scale. It took 65 lives, injured 2,000 people, caused an estimated \$505 million in damage and abruptly brought into focus the vulnerability of California's infrastructure to handle moderate seismic events (defined by magnitudes of 6.5 to 7.0).

Since then, efforts have been made to develop methods to understand and forecast seismic hazards. The 2014 Working Group on California Earthquake Probabilities (Southern California Earthquake Center), using the Third California Earthquake Rupture Forecast Model (UCERF3), forecasted that the probability for moderate seismic events in California is lower than previously predicted.² However, the probability for large (greater than magnitude 7.0) seismic events occurring in the next 30 years is believed to be significantly greater. These studies were conducted after the 2011 Tohoku earthquake in Northern Japan (9.0 magnitude) and the 1999 Chi-Chi earthquake in Taiwan (7.6 magnitude); two quakes that changed the understanding of large seismic events.

New studies have also found that Northern California's Hayward and Calaveras Faults, which extend through the cities of San Jose,

Southern California contains 20 million people, and the City of Los Angeles has been ranked by a major reinsurance company as having the fourth-highest seismic risks in the world after Tokyo, Jakarta and Manila. Los Angeles gets 88 percent of its water from outside its region, and all of its water must cross the San Andreas Fault. If a large-magnitude seismic event occurs, it is projected to damage all of the city's aqueducts and take an estimated 18 months to restore the system. The Los Angeles Department of Public Works (LADPW) has an estimated six months of local storage capacity. LADPW also manages over 7,000 miles of pipelines; some of this distribution system is 100 years old.

- Cardno 2015

Fremont, Oakland and Berkeley, are believed to be continuous and able to generate a large 7.3 magnitude earthquake.³ In addition, the probability of a magnitude 7.8 seismic event on the San Andreas Fault in Southern California is now believed to be approximately 50 percent greater than previously believed.

Recognition of increased seismic risk is not just limited to California. Seismologists now believe that seismic risk is greater for both Oregon and Washington. The Cascadia Subduction Zone that extends along the West Coast from Northern California to Victoria Island is very similar to the subduction zones in Indonesia and Japan that recently experienced large seismic events. The Cascadia Subduction Zone is currently estimated as being able to generate magnitude 9.0 seismic events; therefore, Oregon and Washington are also assessing their infrastructure vulnerabilities.

INFRASTRUCTURE PERFORMANCE HISTORY

In 1994, a 6.7 magnitude Northridge earthquake caused significant damage to the Los Angeles regional water supply system. According to O'Rourke and Toprak, the strong ground shaking "caused damage at 15 locations in the three transmission systems providing water from Northern California, 74 locations in water trunk lines (nominal pipe diameter > 600 mm), and 1,013 locations in the Los Angeles Department of Water and Power (LADWP) distribution pipeline network".⁴ Figure 2 is an Associated Press photograph showing disruption of the gas and water systems in the Northridge earthquake.

A study by Eidinger and Davis in 2012, for the Water Research Foundation, looked at damage to water infrastructure from four different earthquakes:

- 2010 Chili earthquake (magnitude 8.8)
- 2010 Christchurch, New Zealand, earthquake (magnitude 7.3)
- 2011 Christchurch, New Zealand, earthquake (magnitude 6.1)
- 2011 Tohoku earthquake (magnitude 9.0)

The authors found that the bulk of the total earthquake damage to water systems, and the resulting water outages to customers, was due to the failure of hundreds to thousands of smaller diameter distribution pipes in zones of infirm ground.⁵ They also found that existing buried pipe infrastructure remains highly susceptible to damage due to earthquake-caused ground failures (liquefaction, landslide, surface faulting and other effects). Another factor affecting water distribution systems included the loss of large diameter distribution pipelines mainly due to pipe joint slippage, damage to water treatment systems, and loss of power to pumping facilities. By way of comparison, the moderate 6.0 magnitude 2014 South Napa earthquake that occurred in Northern California caused 144 small-diameter water main breaks and damage to only one large diameter water distribution pipeline.

With the current understanding of water system performance and seismic susceptibility of their systems, the West Coast metropolitan areas recognize they must focus on water system resiliency, telecommunication and emergency response infrastructure.

CAUSES OF PIPE FAILURES

California's local water distribution systems are complex. They have been constructed over the last century using varying materials and construction techniques, and many of these systems are approaching the end of their design life. Seismically-induced ground movement applies additional axial and compressional forces on a pipeline, prompting large stresses that can cause pipe splitting, bursting or

collapse (material failure), or inducing soil/pipe movement that results in shearing or pipe joint pullout. Pipe distress, as a result of seismically-induced ground movement, can be grouped into three broad categories:

- Lateral Offset
 - Transverse offset (shearing or connection failure) due to fault rupture (vertical and/or horizontal)
 - Offset from rigid fixed connection (connection to bridge abutments or other structures)
- Lengthening and Rotation
 - Oblique fault offset elongating (pulling) the pipe
 - Settlement induced pipe sag
 - Flotation/heave
 - Lateral earth movement (lateral spreading or slope failure)
- Compression
 - Pipe displacement into fixed point (pipe bend or structure penetration)

Structural factors that could have an impact on pipeline performance during seismic events include:

- Age of materials (fatigue and corrosion)
- Material type (strength)
- Pipe joint type and spacing (mechanical connection or welded)
- Trench installation method (configuration and backfill)
- Depth of installation (applied loading)
- Supporting soil conditions (applied loading)

Seismic ground factors that could have significant effects on the integrity of pipelines include:

- **Fault offset.** The magnitude of ground movement due to fault offset depends on the specific site conditions and fault characteristics. Ground displacement can be abrupt when crossing the actual fault plane with lateral or vertical offset ranging from a few inches to tens of feet in a relatively short distance. Ground displacements can be less abrupt in areas where the faults are overlain by a soil. Fault offset can propagate through a thin overburden soil, or as the overburden soil layer thickens, the displacements occur with the shearing of the soil. In areas where the faults are overlain by deep soil deposits, near surface ground deformations may be relatively minor.
- **Dynamic slope instability (landslide) in natural and manmade slopes.** In general, seismically-induced slope instability is a function of intensity of ground shaking, slope geometry (heights and inclination) and the composition and strength of the earthen materials within the slope.
- **Dynamic densification and/or liquefaction induced settlement.** Dynamic densification can occur in loose, dry and relatively clean coarse-grained (cohesion-less) soils, which results in particle redistribution (densification) from strong ground shaking. Liquefaction can occur in loose, saturated and relatively clean cohesion-less soils where strong ground shaking induces an increase in pore water pressures within the soil deposit. Dissipation of the pore pressures result in densification of the soil deposit. Strong ground shaking can induce large excess pore pressures that can result in an associated loss of soil strength. The loss of strength can result in lateral slope movement, discussed later. The amount of settlement is a function of the ground motion magnitude and both the density and thickness of

the cohesion-less deposit, among other factors.

- **Ground lurching and associated ground cracking.** Ground lurching occurs adjacent to a steep vertical slope face that shifts (“lurches”) toward the unsupported vertical face during shaking. This can result in surface cracking adjacent to the slope and/or slope failure.
- **Lateral slope movement due to liquefaction (lateral spreading).** Strong ground motion can result in development of large pore pressures with an accompanying strength loss. Based upon the site geometry, the strength loss may induce lateral slope movement ranging from a few inches to many feet, commonly referred to as a flow failure. Liquefaction-induced slope movement can occur in gently sloping ground toward a free face, such as a creek or channel.
- **Soil-structure interaction.** When a structure’s response or movement doesn’t match the soil’s response to seismic shaking, facilities supported by or connected to the structures can get damaged.

SYSTEM RESILIENCE BY PREVENTING PIPE FAILURES

In order for water distribution system pipes to be functional after a seismic event, the pipe needs to be able to accommodate movement. Depending on structural factors or seismic ground factors at a given location, this capacity for movement can range from a few inches to several feet. However, preventing all pipe failures is not realistic nor achievable. The goal of a resilient water system is to maintain acceptable distribution capacity immediately after an event by limiting the number of breaks, avoiding breaks at key locations and restoring damaged infrastructure and water services to full capacity quickly.

The City of San Francisco is evaluating deployment of a system of above-ground pipelines to quickly restore both water and natural gas services. The East Bay Municipal Utility District (EBMUD) recently installed a deformable vault on the Mokolume Aqueduct that will expand with lateral movement.⁶ The City of Los Angeles is focusing on upgrading pipelines in the most vulnerable areas (for instance, using high-density polyethylene pipe for its aqueduct where it crosses the San Andreas Fault) and using more resistant pipe material (for instance, importing technology from Japan for more earthquake-resistant pipe).

In highly active seismic areas, or areas where seismic forces are considered more severe, these pipe types can be used in conjunction with mechanical isolation joints capable of accommodating offset, rotation and lengthening. Another technique for accommodating movement is use of geotechnical or geostructural improvements. Such measures can include designing a trench and trench backfill configuration to allow the pipe to move within the trench backfill and designing isolation vaults or structures that can deform and accommodate movement. Ground improvement techniques, such as compaction grouting, densification and soil modification, can also be performed to reduce the magnitude of offset and settlement in order to protect against damage due to liquefaction. However, use of specialized pipe types or geostructural improvements can add significant costs to installation of water distribution systems, so specific studies need to be performed to demonstrate the benefits. Nevertheless, these techniques have proven effective in reducing the number of pipe failures, and ground improvement is a sound mitigation technique.

Upgrading California's pipeline distribution system is currently in the pilot study phase with the cities of Los Angeles, San Francisco and Palo Alto installing earthquake-resistant ductile iron pipe (ERDIP). Manufactured by Kobata Corporation and imported from Japan, this segmental type of pipe incorporates a joint locking mechanism to prevent pipe separation. Joint locking technology was initially developed in Japan in the 1980s and is part of Japanese industry standards. Observations made after the 1995 Kobe earthquake found that pipes with joint locking mechanisms were not damaged in the earthquake, which led to the development of Kobata's current joint locking mechanism design. In their 2012 study, Eiding and Davis did not find any evidence of ERDIP breaks from the 2011 Tohoku earthquake.⁷

As shown in Figure 3, the pipe is a segmented design that provides flexibility, allowing up to 1 percent axial movement and up to 8 degrees rotation to deal with the strains associated with earthquakes, landslides and temperature changes. The pipe lengths bolt together via a rubber flange with its zinc-coated lengths forming an interlinking system that will rotate, flex and not pull apart under pressure. The locking joint design allows the pipe to move with the soil until the locking joint is engaged, which then mobilizes the next segment of pipe like a chain allowing the pipe to deflect with the soil. Due to the increased cost of the ERDIP over standard replacement pipe, installation of the pipe is being limited to strategic pilot projects critical to the city's water system and located in areas with high seismic risk. This includes a pilot project where 6,500 feet of ERDIP will be installed in streets surrounding the Northridge Hospital Medical Facility. This area is especially significant, as it is close to the epicenter of the 1994 Northridge earthquake. The project is expected to be completed in December 2015. Upgrade of the entire Los Angeles system is planned to be completed over the next 20 to 30 years.

SYSTEM RESILIENCE THROUGH ADAPTIVE MANAGEMENT

It is anticipated that a large seismic event will cause severe delivery system disruptions. Figure 4 highlights four critical locations where Los Angeles Basin conveyance systems cross the San Andreas Fault. The potential loss of water supply aqueducts would be catastrophic for San Diego, Los Angeles and other communities, resulting in complete cutoff from their existing water supplies. Outages of up to 18 months have been forecast while existing local water storage capacity is estimated to be limited to six months.

In response, San Diego developed its Emergency Water Storage Project that includes enlarging and strengthening the Olivenhain and San Vicente dams and related pipelines and pump stations, specifically to increase the resilience of its water system. The improvements at Olivenhain Dam also include a pump storage project to generate electricity that offsets the cost of the program.

Los Angeles, San Francisco and EBMUD have upgraded and expanded their water storage and pumping facilities. EBMUD has retrofitted its Mokelumne Aqueduct to have locations of controlled breaks, should it experience severe offsets, and has planned local storage with sufficient capacity to endure during the time needed for restoration of service.⁸

Additionally, alternative water use technologies are being explored. The City of San Diego has invested in a micro filtration and treatment pilot program to treat its tertiary treated wastewater for reuse as potable water. Once the process is approved, the treated water will be pumped back into the reservoirs for fresh water blending to aug-

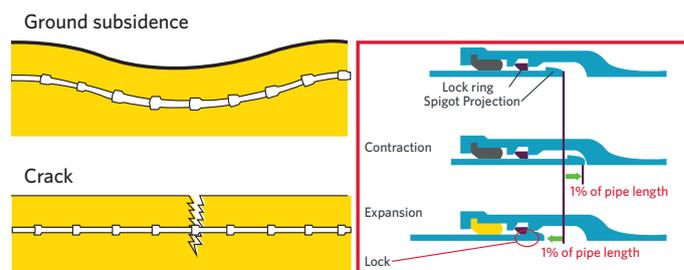


Figure 3. ERDIP Locking Joint Design.
Source: Haddaway 2015/Kabota Corporation

ment the water supply. California cities are also evaluating the use of recycled water and possible desalination of sea water for use in emergency response firefighting to save potable water supplies.

CURRENT CALIFORNIA INVESTMENT

Water agencies in California have begun to invest billions of dollars to evaluate and begin improving the seismic resiliency of their water supply, storage and distribution facilities. For example:

- **San Francisco:** In 2001, the San Francisco Public Utilities Commission initiated the Water System Improvement Program (WSIP) to increase water supply reliability, delivery reliability and seismic reliability. The \$4.5 billion program includes about 40 regional projects designed to reduce risk from seismic events and to improve system reliability by providing redundancy for facilities that convey water from the Sierra Nevada to the Bay Area. This also includes about 40 projects within San Francisco designed to enhance reliable water deliveries, update outmoded equipment and rehabilitate aging infrastructure to withstand seismic events. It is one of the largest water infrastructure programs in the country and is about 90 percent complete.
- **Oakland:** Seismic resiliency has been a top priority for EBMUD since 1994 when the utility adopted a 10-year, \$189 million Seismic Improvement Program (SIP) for its water distribution system.⁹ EBMUD's seismic improvement efforts have continued since the completion of the SIP, including the investment of \$39 million into seismic improvements of the Mokelumne Aqueduct.
- **Los Angeles:** In December 2014, Los Angeles Mayor Eric Garcetti announced a plan called Resilience by Design, aimed at reducing the city's earthquake vulnerabilities.¹⁰ The goal is to be proactive with respect to seismic design. The plan embraces fortification of the city's water supply, including:
 - Development of an alternative system for firefighting
 - Fortification of the Los Angeles Aqueduct crossing the San Andreas Fault
 - Fortification of other aqueducts crossing the San Andreas
 - Fortification of water storage (seismic resiliency of LADWP dams)
 - Increase in local water sources (stormwater capture, water conservation, water recycling and remediation of contamination in the San Fernando Basin groundwater)
 - Development of a network of resilient pipelines
 - Development of a statewide seismic resilience bond measure

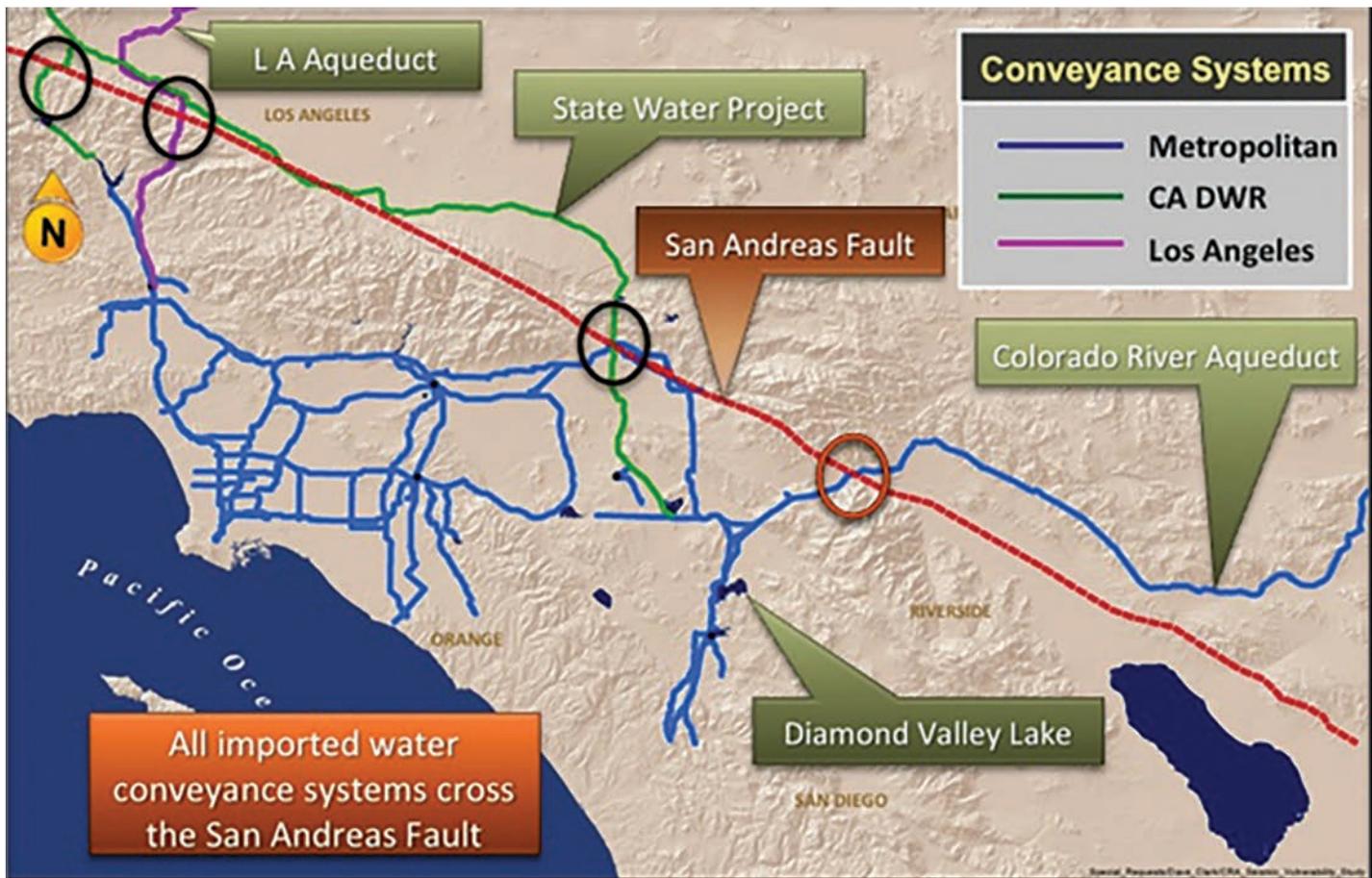


Figure 4: Aqueduct Fault Crossings. Source: Totten 2014

CALIFORNIA'S FUTURE

Communities in California are dependent on aqueducts and pipelines to provide clean, potable water. Pressures due to long-term drought make limited fresh water sources even more valuable. Growing populations increase reliance (and dependence) on pipelines. A resilient water distribution system is critical for people living in a seismically active area. California utilities and government entities have recognized this need for resilience, and water resiliency projects are underway statewide.

Although funding is not limitless and system upgrades often must take place over the course of years, renewed focus on resiliency, adaptive management and construction of strategic projects is resulting in considerable progress. While we cannot predict earthquakes and the associated damages, it is recognized that large-magnitude earthquakes will occur in the future and challenge California's pipeline systems. Because these water supply systems are critical infrastructure, the systems must survive earthquakes, or must be capable of being restored quickly in the aftermath of earthquakes. This will enable urban areas to survive and continue to thrive.

As summed up by Councilmember Mitchell Englander, who represents the Los Angeles 12th District that includes Northridge, on the 21st anniversary of the Northridge earthquake, "There is no life without water, and access to clean, potable water after a major earthquake will make the critical difference in how many lives are saved and how quickly our City rebounds."¹¹

¹Rockefeller Foundation. (2015). "What is Urban Resilience?" <http://www.100resilientcities.org/resilience#/-/>

²Field, E. H., and 2014 Working Group on California Earthquake Probabilities. (2015). UCERF3: A New Earthquake Forecast for California's Complex Fault System. *U.S. Geological Survey 2015-2009*.

³Maffei, J., & Knudsen, K. (2010). The Coming Bay Area Earthquake: 2010 Update of Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault. *The Earthquake Engineering Research Institute-Northern California Chapter*.

⁴O'Rourke, T., & Toprak, S. (1997). Using GIS to Assess Water Supply Damage from the Northridge Earthquake. *In Proceedings from the NCEEER-INCEDE Workshop on Earthquake Engineering Frontiers in Transportation Facilities*.

⁵Eidinger, J. M., & Davis, C. A. (2012). Recent earthquakes: implications for US water utilities. *Water Research Foundation*.

⁶East Bay Municipal Utility District. (2011). *Annex to 2010 Association of Bay Area Governments Local Hazard Mitigation Plan, Taming Natural Disasters*.

⁷Haddaway, A. (2015). Earthquake-Resistant Ductile Iron Pipe Makes U.S. Debut in Los Angeles. *Water World*, 31(4).

⁸Swenson, T., Maison, B., and Goodson, M. (2004). "Seismic Mitigation - Mokelumne Aqueduct No. 3 East Bay Municipal Utility District." *American Society of Civil Engineers, Pipeline Engineering and Construction*, 1-9.

⁹East Bay Municipal Utility District. (2006). *Seismic Improvement Program: 2004/2005 Progress Report*. <http://cdm16658.contentdm.oclc.org/cdm/ref/collection/p267501ccp2/id/1614>.

¹⁰Garcetti, E. (2014, December 8). Resilience by Design: Mayoral Seismic Task Force Report for Los Angeles. *City of Los Angeles*.

¹¹Englander, M. (2015). "LADWP Installs Earthquake Resistant Pipes for Drinking Water around Northridge Hospital." *City of Los Angeles*. http://cd12.lacity.org/MediaRoom/News/LACITYP_029690.

Sources Cited in Graphics:

Cardno, C. A. (2015). Preparing for the Big One. *Civil Engineering*, 85(2).

Lauder, T. S. (2014, December 16). Earthquake Threats to California's Water. *LA Times*.

Totten, S. (2014, December 26). LA could lose 70 percent of its water in the next 'big one.' *Southern California Public Radio*.

For more information about this article,
please contact Mark Stanley
at Mark.Stanley@hdrinc.com

Long Range Water Supply Plan for the City of Dallas

By Cory Shockley, PE

Integrated Water Planning Project Manager, Austin, TX



City of Dallas downtown skyline

The year of 2011 was one of the hottest and driest years on record for much of Texas. Water suppliers across the state were facing dwindling supplies, mandatory cutbacks and budget shortfalls. The combination of high temperatures and increased evaporation with little rainfall and even less runoff resulted in water supply reservoir levels reaching historic lows. Common questions among water suppliers included:

- Is this the new drought of record?
- When will it rain again?
- Where will we go for water when our lake runs dry?
- What could we have done to be better prepared for these conditions?

Dallas knows the answer to this last question. In fact, during the recent drought, the Dallas water supply system performed as planned, and Dallas weathered the drought quite

well compared to other cities in the state. Cutbacks were initiated according to its drought contingency plan and conservation was encouraged across the customer base, but the real success of the system can be traced back to the planning efforts of previous city leaders who endured (survived) the drought of the 1950s. The actions of these leaders established the practice of developing and executing water supply plans to produce a resilient water supply for the citizens and customers of Dallas. Fittingly, the most recent update to the Dallas Long Range Water Supply Plan (LRWSP) occurred during the driest months of the most recent drought. The LRWSP is a 50-year plan to identify Dallas' demands, quantify supply from existing sources, calculate needs and identify new water supply projects to meet the needs of the city and its customers for the next 50 years.

CHALLENGES AND SOLUTIONS

HDR was hired to lead the development of the Dallas 2014 LRWSP. The main drivers considered in the LRWSP are increasing demands, decreasing supplies and climate variability. Specifically, the climate variability aspect of the planning effort was focused on addressing droughts more severe than the historic droughts of record. We began the planning process with a goal in mind, to develop not only a reliable plan but one that incorporates multiple aspects of sustainability to serve Dallas for 50, 70 or even 100 years while building on the resilient system that has been put into place through planning and execution by city leadership for several decades.

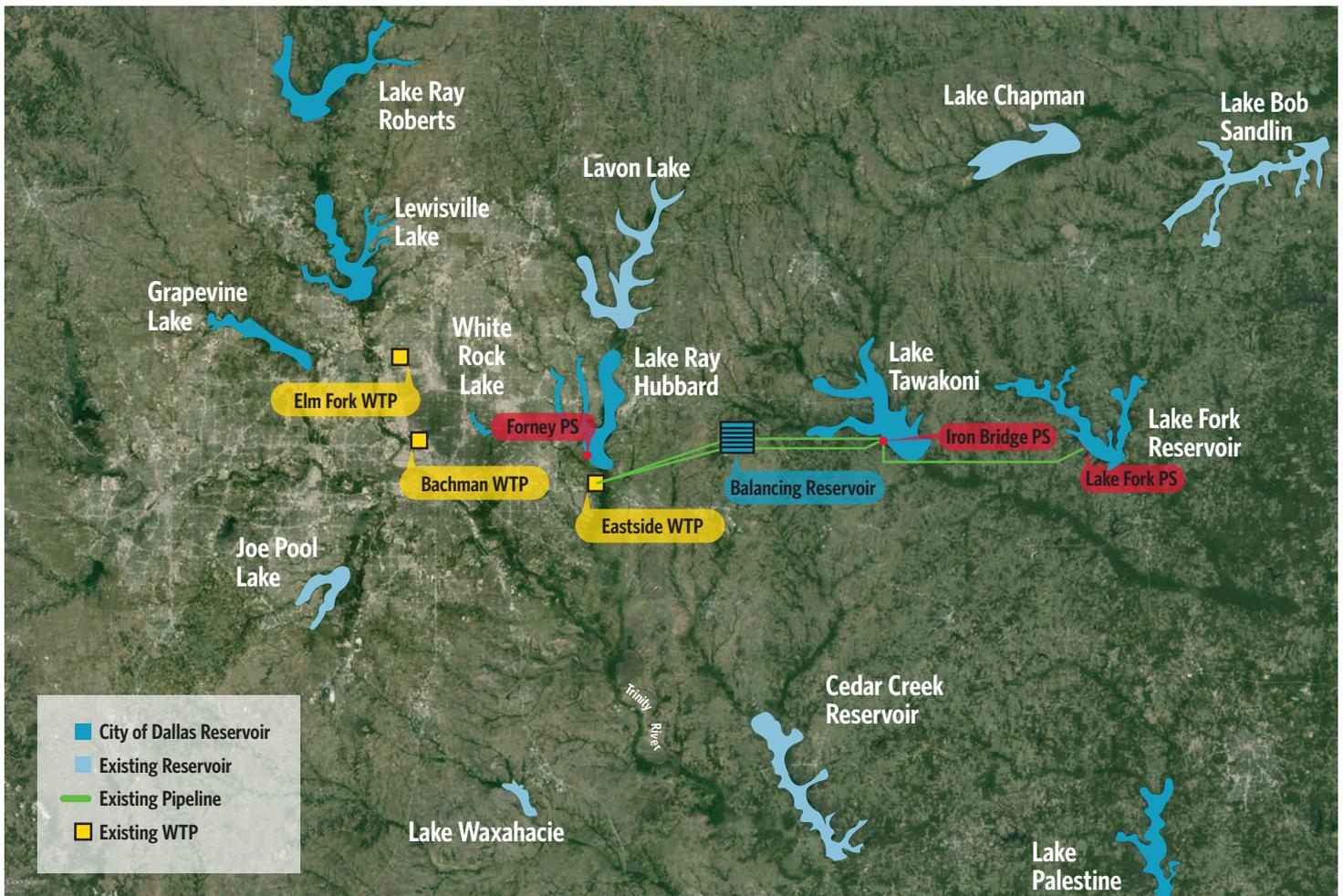


Figure 1: City of Dallas Water Supply System

As shown in Figure 1, the Dallas water supply system is comprised of six connected water supply reservoirs, shown in dark blue, all located within about an 80-mile radius of the city. These reservoirs are connected to three water treatment plants that provide potable water to 11 major pressure planes. Dallas also has one unconnected reservoir, Lake Palestine, also shown in dark blue on the figure, which will be connected to the Dallas system in the next decade.

The population of Dallas and its customer cities is expected to increase over 70 percent, reaching over 5.2 million people during the 50-year planning horizon. Taking into account more efficient fixtures and building codes, it is estimated that the

water demand over this same period will increase over 50 percent to an average annual use of 718 million gallons per day (MGD).

Sustainability and resiliency were common themes throughout the development of the LRWSP. We recommended that Dallas continue its conservation efforts and implement the best management practices identified in its strategic water conservation plan to achieve an additional 13 percent reduction in future demands. We also identified and recommended a 100 MGD indirect potable reuse project that involves Dallas diverting effluent discharged from its two wastewater treatment plants into a large off-channel reservoir for storage and subsequent transmission to and treatment

at its water treatment plants. This project will allow Dallas to maximize its supplies without appropriating additional state water.

Like all reservoirs, Dallas' supply reservoirs are subject to sedimentation and evaporation. These two components were evaluated in the LRWSP with a specific look at how supplies from existing sources could be impacted by these factors. We estimate that Dallas' existing reservoirs will lose 9 percent of the available storage capacity (310,000 acre-feet) due to sedimentation, which results in a 4% loss of supply over the planning horizon. As discussed in detail below, we estimate that with the effects of climate variability (higher temperature and increased evaporation), Dallas could see an additional 13 percent

reduction in available supplies by 2070 if climate change results in a 7 degree Fahrenheit increase in average daily air temperature. We developed a plan to address these issues by recommending strategies that not only meet the future needs but produce a buffer, or safety factor, to provide for a more resilient system, better capable of bouncing back from harsh conditions.

MODELING FOR CLIMATE UNCERTAINTY

Dallas Water Utilities staff envisioned the future by working with our modeling experts to develop and apply a system-specific Dallas Water Supply Model (Dallas System model) using the RiverWare software package, which simulates all components of Dallas' complex raw water supply system. The Dallas System model is an essential tool not only in evaluating water supply options but in determining how a potential supply can be integrated into the Dallas system.

The Dallas System model incorporates 101 years of historical hydrologic data including streamflow, evaporation and precipitation to evaluate Dallas' supply system and plan for a repeat of the most severe drought conditions on record. In the past, water supply planners have always used the fundamental approach that history is destined to repeat itself and the past is our best indication of the future...but what if that approach is wrong? What if we are venturing into uncharted territory due to long-term climate trends and the future will be nothing like what we have witnessed in the past? The recent drought in Texas, which was the most severe on record for many parts of the state, led to many of these tough questions and to another one: How do we model climate variability from a water supply perspective and quantify the associated risk?

For the Dallas LRWSP, the answer to this last question included using a combination of historical data and climate projections. Our engineers reviewed various emission scenarios before selecting the A1B emissions scenario. Scenario A1B, illustrated in Figure 2, is considered a middle-of-the-road scenario and assumes rapid world population growth peaking around 2050 before declining throughout the rest of the 21st century. The A1B scenario assumes a balance between fossil and non-fossil energy sources.

Output from eight Global Climate Models (GCMs) was used to create a multi-model mean of projected air temperature increases for the A1B scenario throughout the planning period of the Dallas LRWSP (2020-2070). Impacts to precipitation and streamflow were not considered for the Dallas LRWSP because of the high degree of GCM uncertainty associated with these parameters. GCM output is produced at a large spatial scale and, while useful for regional assessments, is not applicable to the smaller study area containing Dallas' water supply reservoirs. Therefore, downscaled GCM output data was obtained from the World Climate Research Programme for the study area. As shown in Figure 3, the downscaled GCM temperature output projected a 2 degree Fahrenheit (F) increase in temperature from historical average temperatures by 2020 and a 7 F increase by 2070.

The Dallas System model includes monthly historical gross evaporation data for all of Dallas' supply reservoirs. Therefore, the projected temperature increases were translated to increases in reservoir evaporation and incorporated into the model. A relationship between historical gross evaporation and historical average monthly

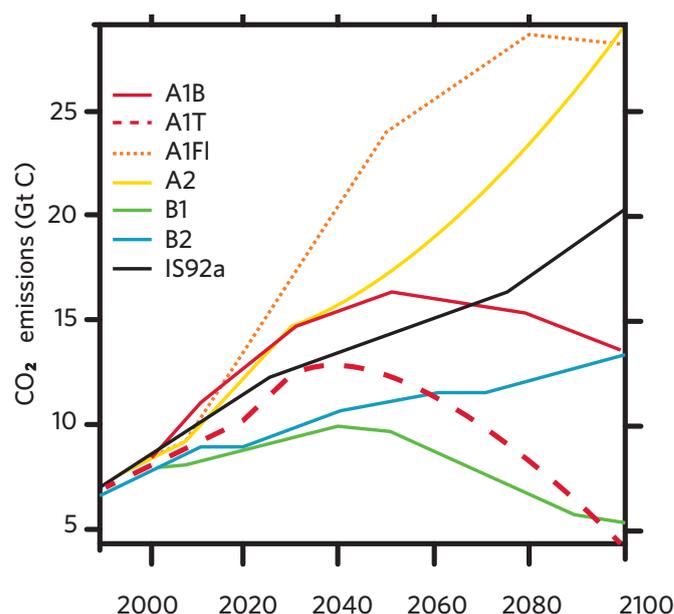
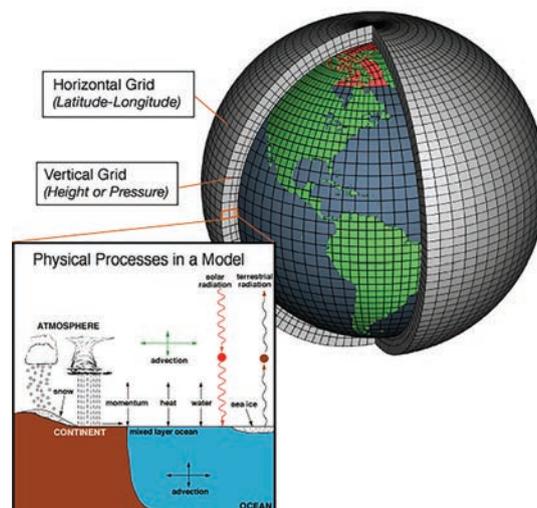


Figure 2: GCM Scenarios and Downscaling Schematic. Source: IPCC Special Report on Emissions Scenarios



Schematic showing physical processes in the model. Source: NOAA

Year	Mar. - May	June - Feb.
	Δ Temperature ($^{\circ}$ F)	Δ Temperature ($^{\circ}$ F)
2020	2	2
2070	7	7

Figure 3: Potential Increases in Temperature (from Historical) for Dallas Reservoirs

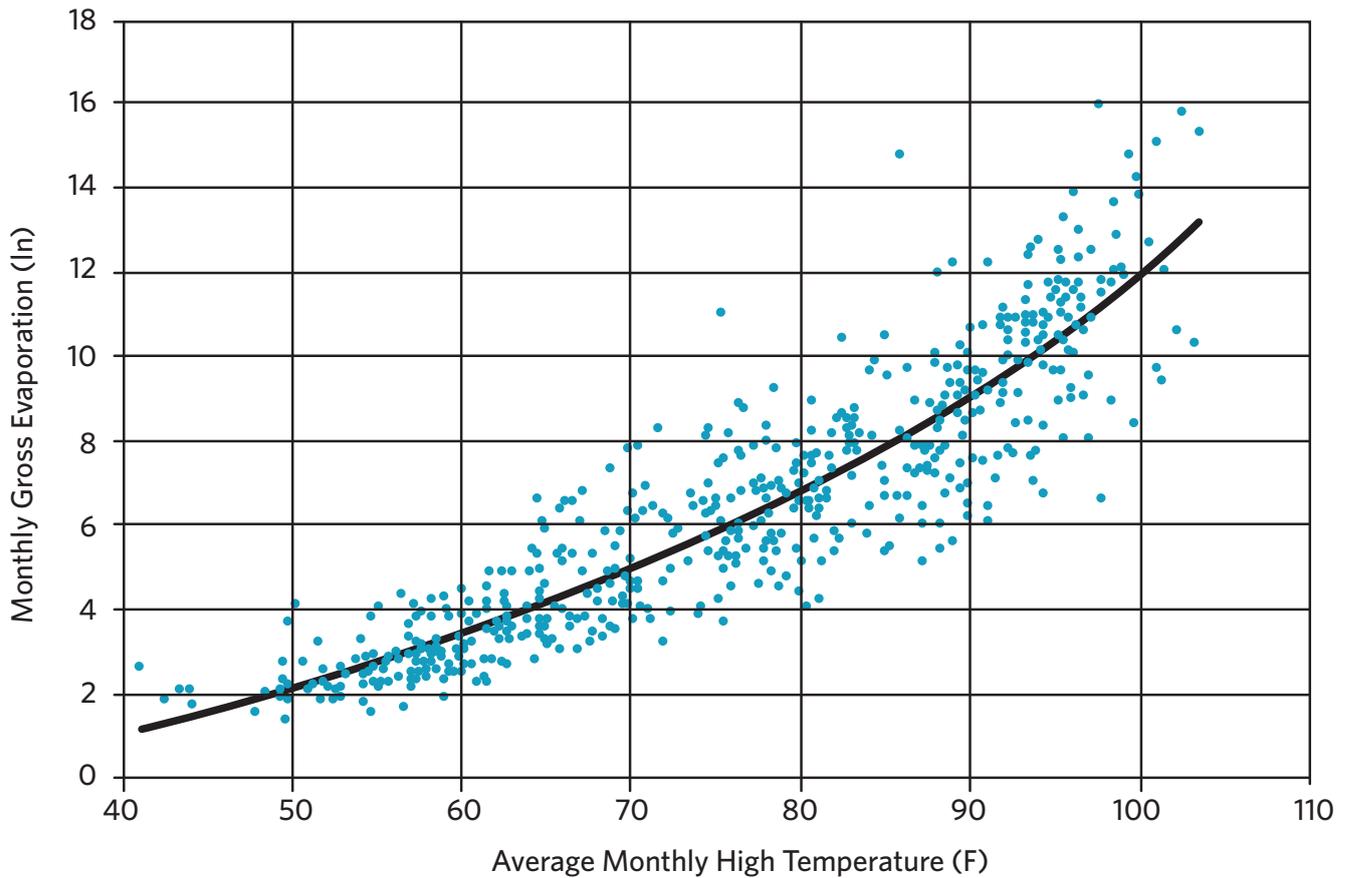


Figure 4: Historical Comparison of Monthly Gross Reservoir Evaporation and Average Monthly High Temperatures

high temperatures at Lake Grapevine was developed to calculate the increase in gross evaporation from temperature increases. Figure 4 shows that an exponential increase in gross evaporation is present with an increase in temperature. Our team researched this relationship more extensively (in Figures 5 and 6) and found that a bi-seasonal (spring and summer/winter/fall) exponential relationship provided a higher degree of certainty in calculating gross evaporation from temperature.

Historical gross evaporation at each of Dallas' reservoirs was adjusted to reflect the potential impacts of a 2 F and 7 F temperature increase from climate variability. Figure 7 provides an example of how a historical monthly gross evaporation value recorded in a summer month was adjusted for a 7 F temperature increase. An average monthly high temperature is calculated using the summer/fall/winter regression equation. The calculated temperature is then raised by 7 F, and the same regression

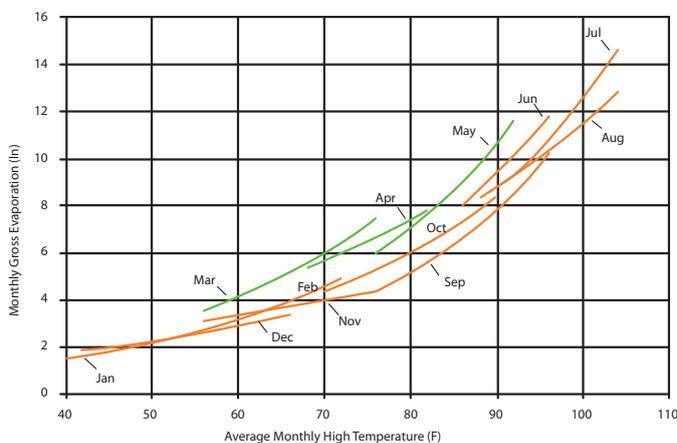


Figure 5: Historical Monthly Correlation of Gross Reservoir Evaporation and Average Monthly High Temperatures

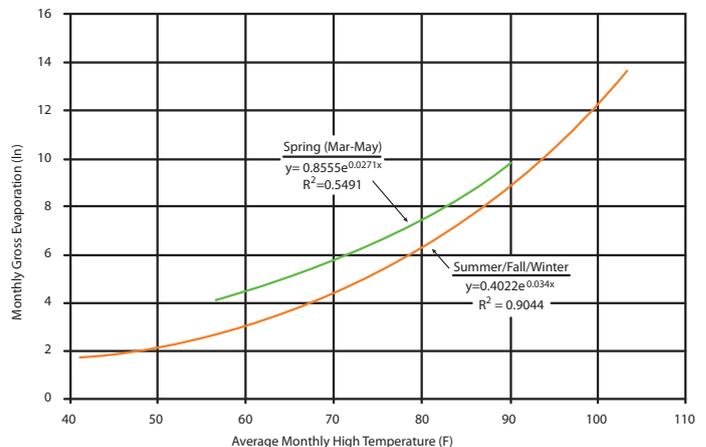


Figure 6: Historical Seasonal Correlation of Gross Reservoir Evaporation and Average Monthly High Temperatures

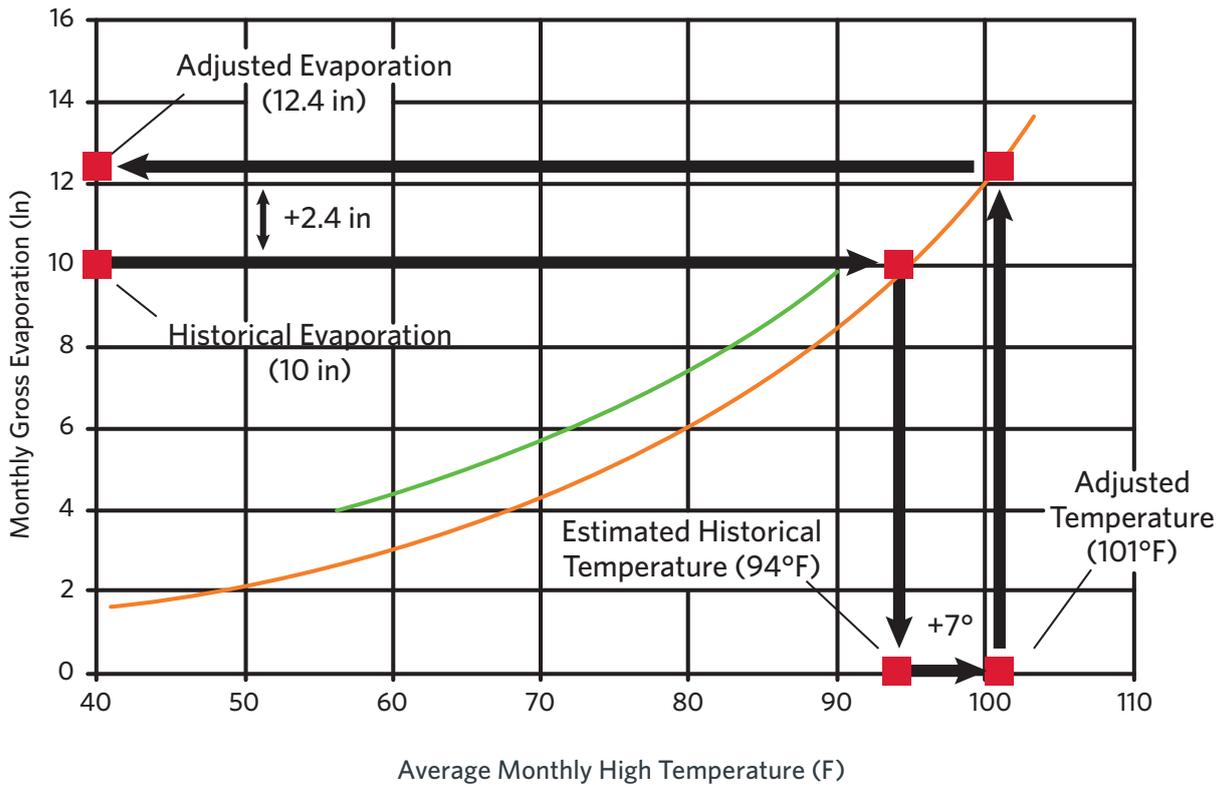


Figure 7: Gross Evaporation Adjustment from Temperature Increase (2070 Summer Example)

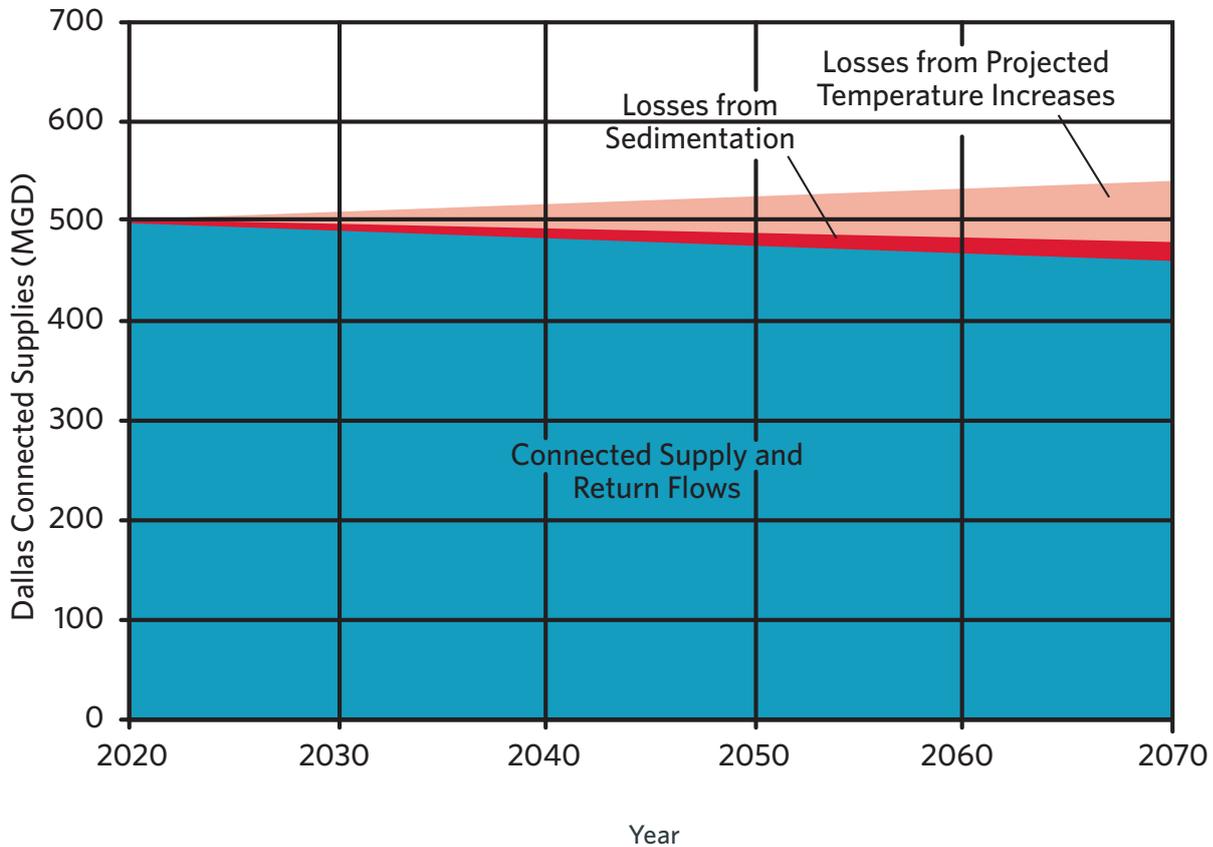


Figure 8: Dallas' Current Supplies and Losses from Sedimentation and Climate Variation

(continued on back cover)



8404 Indian Hills Drive
Omaha, NE 68114-4098

PRSRT STD
US POSTAGE
PAID
OMAHA, NE
PERMIT NO. 963

hdrinc.com

WATER SUPPLY

(continued from page 21)

equation is used to estimate a projected monthly gross evaporation resulting from the temperature increase. This calculation was performed for every month of the 101-year hydrologic period of record in the RiverWare model to create two additional gross evaporation databases for use in model simulations.

Model simulations performed as part of the Dallas LRWSP revealed that projected supply losses in 2070 from climate variability are approximately three times larger than the losses expected to occur from reservoir storage reduction due to sedimentation (Figure 8). As a result, future water supply strategies must not only meet future needs from growing demands but also reduce the risk associated with climate uncertainty.

THE PATH FORWARD

In developing the Dallas LRWSP, our team analyzed demand forecasts, quantified available supplies and identified and evaluated strategies and implementation scenarios with the goal of creating a more resilient water supply. We created population and demand estimates and applied climate change model results to forecast

future water supplies and associated needs. We developed an evaluation matrix to identify which strategies made the most sense economically, politically, environmentally and strategically. Ultimately, we recommended six water management strategies to meet Dallas' water supply needs through 2070 and beyond. Seventy-five percent of these strategies rely on conservation, reuse and connection to existing supplies. Connection to new surface water supplies is not recommended until after the 2060 decade.

The plan offers a clear pathway for Dallas to provide a consistent water supply for their customers for the next 50 years and beyond. We looked at many details of the Dallas system and delved into many system variations. The result is a solution unique to Dallas that provides a pathway to 2070 with a focus on handling challenging conditions (drought and increasing demands). This plan proactively applies strategies that will enable Dallas to provide reliable supply in the face of new, more severe droughts occurring during times of growth and increased demands.

*For more information about this article,
please contact Cory Shockley, PE
Cory.Shockley@hdrinc.com*