

Current and Future Climate Changes Relevant to Infrastructure	Sector	Vulnerabilities	Risk	Adaptation Strategy Recommendations	Co-benefits and Synergies Across Sectors
Higher Temperatures during summer months and extreme heat events	Transportation	Buckling of roadways and/or bridges due to concrete expansion and softening of bituminous pavements	State maintains over 40,000 miles of roadways and 25,000 bridges . Local system includes over 70,000 miles of roadway and 6,300 bridges over 20 feet in length and an unknown number of bridges less than 20 feet.	Review available research for potential materials that can withstand higher temperatures	
	Transportation	Higher temperatures may impact construction schedules due to impacts on materials and personnel	Materials may not set or cure due to higher temperatures and works are more susceptible to heat related injuries	Perform work activities during cooler portions of the day, i.e. work during the night time hours	
	Transportation	Buckling of paved runways	Pavement deformations create a hazard to aircraft tires during critical high-speed takeoffs and landings.	More frequent inspections and installation of heat/pressure sensors in the pavement for real-time anticipation of failure.	
	Transportation	Thermal misalignment of passenger and freight railways	Extreme heat can cause rail lines to expand creating the phenomenon known as a sun kink or nervous rail. This adversely affects the rail gauge and if left unrepaired could cause trains to derail.	More frequent inspections and additional tie anchors will need to be installed to all of the approximately 12,000 miles (2 rails per 6,000 liner miles of track) of track in the Commonwealth.	
	Transportation	High impact thunderstorms	Increased risk of lightning strikes, hail and tornados causing airport closures, delays and flight diversions	Improve forecasting techniques Prepare for flight delays and diversions	
	Transportation	Invasive plant species management	Invasive species encroach on right of way and limit sight distances causing safety issues.	Research and employ herbicide management techniques to control invasive species	
	Energy	Invasive plant species management, faster growth of trees.	Damage to equipment from vegetation. Additional costs for vegetation management - more manpower spent on vegetation management. As power lines heat up, they may sag, touching trees, shorting out and causing outages.	Continued vegetation management research to develop cost effective strategies.	

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Higher Temperatures during summer months and extreme heat events	Energy	Higher overall demand for energy from existing generators for cooling	A 1.8 degree average increase in temperature will require 5-20% more power generation in PA.	More renewable energy generators, more demand response and support for energy efficiency standards. Smart grid technology - including price responsive demand which allows consumers to cut their power usage as demand increases and prices increase. Additional funding for solar projects to reduce demand from fossil fuel generators during hottest times. New building standards for existing and new construction - better insulation, better window glazing in new and existing homes. Tree planting and use of roof materials to reflect heat to combat "heat island" effect. Continued funding for the Keystone Help program that provides loans for energy efficiency upgrades for homeowners.	
	Energy	Higher peak demand requiring new generation	To ensure reliable electric service, more generation may be needed as the highest demand days increase in total power needed and the number of days of high demand.	Reduction of peak demand as above. Smart grid and price responsive demand to lower peaks.	
	Energy	Decrease in transmission efficiency as temperature rises - higher demand needed to meet existing load	As demand increases, the temperature of transmission lines increases, causing the lines to sag. As the temperature of a line increases, its ability to transfer electricity decreases causing more demand just to meet existing load. Can result in the loss of the line, property damage from fire and wildfires.	Update transmission and distribution system design standards.	

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Higher Temperatures during summer months and extreme heat events	Energy	Lower reliability caused by higher demand, less generation, more congestion (too much demand trying to go thru the same pathways) - will result in more brown-outs (voltage drops) and black-outs (complete loss of power).	More brown-outs and black-outs will impact the economy of the region and health and safety of Pennsylvanians.	Incorporate climate forecasts in the transmission planning process rather than relying on historical weather forecasts. Update transmission and distribution design standards.	
	Energy	Difficulty in siting new generation as air quality deteriorates	Increased congestion of power flow - leading to higher costs and more failures.	Incorporate climate change impacts in transmission planning processes.	
	Water	Warmer water temperatures may require pre-treatment prior to use by some industrially permitted uses	Water consumptive businesses will need to alter operations or relocate if changes are cost prohibitive	Temperatures may be moderated by riparian buffers along a corridor	
	Water	Warmer water temperatures, especially extremes of duration, will host water quality changes that will require changes to treatment used by municipal drinking water suppliers	Municipal suppliers will need to include adaptation planning to achieve full asset management	Municipal plans will encourage watershed wide temperature moderating features such as buffers	
	Water	Warmer water temperatures will require industrial discharges to moderate discharge volumes or temperatures to meet water quality standards	Industrial wastewater permit holders will need to meet water quality standards with applied technology, alter operations or relocate	Discharges may be moderated with the use of vegetated retention prior to the point of discharge; permit writers and enforcement staff will need to exercise additional diligence	
	Water	Warmer water temperatures will require municipal wastewater dischargers to do more to meet standards to avoid harmful levels of bacteria and other pollutants	Municipal wastewater dischargers will need to include adaptation planning in asset management and LTCPs for CSOs	Municipal plans should prioritize CSO elimination and reductions in imperviousness and limit new impervious areas	

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Wetter winters - more intense winter storms	Transportation	Winter Flooding - increased damage due to ice dams and other debris blocking water flow	Increased funding required for emergency maintenance, safety and economic issues due to flooded roads and bridges	Change design standards for areas that may be prone to flooding	
	Transportation	Roadway degradation due more water in the soil and increased freeze/thaw cycle.	Increased funding required to fix potholes and supportive road bases	research and employ different materials that do not allow moisture to penetrate road surfaces	
	Transportation	Runway degradation due to more water in the soil and increased freeze/thaw cycle.	Pavement deformations create a hazard to aircraft tires during critical high-speed takeoffs and landings.	More frequent inspections and airports may need to purchase pothole repair equipment in order to facilitate real-time safety repairs.	
	Transportation	Wind shear	Closing airports	Airports will need to design additional terminal space for feeding and housing stranded passengers as well as purchasing additional forecasting equipment.	
			Aircraft mishap	Develop and implement new aircraft parking requirement Cancel and divert more flights	
	Transportation	Erosion of rail beds and ballast	Many railroads parallel rivers and streams making them extremely susceptible to erosion, undercutting or complete washout.	Increased inspection and construction of a comprehensive levee system.	
	Energy	Transmission and distribution problems.	Reliability issues and more outages.	Use weather forecasting that takes into account climate change rather than relying on past weather patterns only.	
Water	Increased winter stormwater runoff increases pollutants associated with road treatment	Water treatment facilities burdened; municipal stormwater permits require modification; non-point runoff impacts water quality	Best Available Technology for road treatment must advance; road and parking lot buffers and vegetated filters required		
More Extreme Heat Events	Energy	Too much demand for electricity may overload the grid - grid manager would have to shed load (cut off demand) - resulting in brown outs and blackouts	Reliability issues and more outages.	Update transmission and distribution system design standards.	

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More high impact storms with more flooding	Transportation	More damming effect at bridges leads to the potential for greater loss of structure and property damage adjacent to transportation infrastructure	Higher insurance rates for property owners and washed out bridges cause lengthy detours	Consider relocation of roadways located in floodplains?	
	Transportation	Closure of airports due to high impact weather events	Delays to inbound and outbound aircraft as well as increased hazards to in-flight aircraft due to additional icing and wind shear.	Airports will need to design additional terminal space for feeding and housing stranded passengers as well as purchasing additional de-icing and forecasting equipment.	
	Transportation	Extreme cold weather events exacerbate micro-structural flaws in passenger and freight rail.	Each time a micro-structural defect is subjected to extreme cold it may grow in size, increasing the odds of structural failure.	Increased non-destructive inspections such as ultrasonic inspections	
	Transportation	Ports of Philadelphia and Erie are susceptible to flooding due to storm surge	Increased wave action and flooding may damage or destroy docks and freight handling equipment	Construction of moving seawalls	
	Transportation	Shipping interests in the Port of Pittsburgh due to its narrow channel	High wind causing ships to run aground outside of the channel	Do not operate shipping interests during high impact storms.	
			Flooding causing fast currents and high water	Do not operate shipping interests during high impact storms.	
	Transportation	More need for emergency operations and maintenance on both bridges and adjacent properties due to increased flooding.	more funding spent on emergency operations and not devoted to maintenance	Change design standards or move roadways to prevent flooding	
	Transportation	Increased erosion of soil and sedimentation deposits in streams, waterways and stormwater retention systems	Loss of transportation infrastructure structural support and carrying capacity of waterways and stormwater retention systems.	More intense inspection of transportation infrastructure after flooding events for those areas susceptible to erosion.	
	Energy	More damage to transmission and distribution lines - flooding of both above and underground lines and equipment	Reliability issues and more outages.	Identify at risk facilities - protect, move or add redundancies.	
Water	Existing infrastructure stressed by increased water volumes	Gap between needs and resources for wastewater and drinking water infrastructure will grow; the list of high hazard dams and flood walls will increase	Green infrastructure practices to retain water and reduced imperviousness incentivized and funded; high hazard dams repaired or removed; instream hard infrastructure with outmoded uses replaced by natural		

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Drier summers - drought	Energy	Decrease in water availability for generation cooling and for hydropower generation	Nuclear plants, large coal plants and other generators could be curtailed when river levels fall or by thermal limits on water discharge. A 1% decrease in stream flow causes a 3 percent drop in power generation from hydropower.	Identify at risk facilities. Develop additional cooling strategies.	
	Water	Water users will be challenged to maintain necessary instream flow levels; balance amongst competitive uses will be required	Permitted withdrawals will require modification; more watersheds and sectors will require permitting or planning	A permit withdrawal system that addresses cumulative impacts to protect quality and supply and incentivizes conservation	
	Water	Water dischargers will be challenged to maintain some operations and still achieve permitted pollutant limits	Models for discharge allocations and associated permits will require modification; feasibility of some activities may require new technologies or larger receiving waterbodies	Development siting must address wastewater capacity; re-use practices incentivized	
Sea level rise- salt water intrusion	Energy	May impact water intakes on Delaware River	Could cause corrosion or cooling problems.	Identify at risk facilities - protect, move or add redundancies.	
	Transportation	At three feet above sea level, the port of Philadelphia would be flooded by an expected 1 to 2 meter sea level rise.	Loss of ship yard to include dry dock and repair facilities	Private companies may be required to relocate or abandon critical infrastructure.	
			Loss of largest fresh water port in the country.	Move the port further inland at the cost of moving a comprehensive rail yard and sections of the city of Philadelphia	
	Transportation	Underground subway/trolley lines may flood resulting in increased need for pumping and tunnel sealing.			
	Transportation	The fresh water port of Philadelphia could become a salt water port	Increased barnacle growth on piers and pilings	Increased inspections and cleaning cost	
Water	Water intakes along the Delaware River may become have increased salt levels	Water supplies may require additional treatment or intakes may require relocation; municipal suppliers may need to purchase water from upstream sources	Conservation and re-use practices will reduce costs to municipalities forced to address salt infused supplies		