| **Step 2: Assess Climate Impacts & Vulnerabilities** |
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| **COMMUNITY NAME:** *Chesapeake Bay*  |
| **Indicators of a Changing Climate** |
| **Climate Threat** | **Impacts** |
| **Indicator** | **Magnitude and direction of change over time based on community knowledge and latest climate science** | **Changes in environmental conditions** **(Climate Stressors)** | **Potential impacts to natural and social resources** |
| **Atmospheric CO2 concentration (tidal wetlands only)** | **CO2 concentration in the atmosphere has been increasing and will continue to increase under a variety of scenarios.***Historical: The preindustrial CO­2 concentration was around 280 ppm.**Projected: Depending on the emissions scenario, CO2 concentrations could range from 400-1200 ppm by the end of the century.* | *Altered atmospheric and surface water chemical composition, altered carbon cycle* | *Tidal wetlands only: Shifts in community composition due to differential responses to increased atmospheric CO­2,**SAVs only: Increased temp alone causes SAV dieback, but warming with doubling of CO2 leads to regrowth (Zimmerman et al. 2015).* |
| **Air temperature (tidal wetlands only)** | **Air temperature has increased and is projected to continue to increase throughout the watershed***.* *Historical: 0.23°C increase per decade from 1960 to 2010 (Rice and Jastram 2014). 1°C increase in last 110 years in Pennsylvania (Shortle et al. 2015). The Bay freezes less frequently than it did during mid-20th century (Boesch 2008).* *Projected:* *Downscaled RCP8.5 climate models (CMIP5) predict 3-3.3°C of warming across Pennsylvania by mid-century (Shortle et al. 2015). Heatwaves are predicted to dramatically increase in frequency by the end of the century under the A1B scenario (Meehl et al. 2007).* | *Warmer temperatures, higher rates of evapotranspiration* | *Tidal wetlands only: Increased wetland accretion rates due to increased growth which mitigates sea level rise, increased chance of invasion by species like* Phragmites australis*SAVs only: Increased temp alone causes SAV dieback, but warming with doubling of CO2 leads to regrowth (Zimmerman et al. 2015).* |
| **Stream and Bay temperature (SAV and tidal wetlands only)** | **Water temperature has increased and is projected to continue to increase throughout the watershed***.* *Historical: 0.28°C increase per decade from 1960 to 2010 (Rice and Jastram 2014). 1990s were about 1 °C warmer than the 1960s (Najjar et al. 2010).* *Projected: Six scenarios’ temperature increases range from 3 to 6°C by 2070-2099 (Najjar et al. 2009).*  | *Reduced oxygen solubility, increased hypoxia and anoxia, increased Bay summer-time stratification*  | *Earlier planktonic spring bloom, increase in respiration relative to photosynthesis, increased growth of* Enteromorpha *and* Ulva *seaweed, increased frequency and kinds of harmful algal blooms, shifts in species’ spatial distributions due to temperature sensitivity**SAV only: Altered success of species due to different temperature ranges, mortality in combination with low water column mixing, increased growth of epiphytes that reduce light availability**Tidal wetlands only: Increased chance of invasion by species like* Phragmites australis*,*  |
| **Sea level (SAV and tidal wetlands only)** | **Sea level has risen and is projected to continue to rise in the Chesapeake Bay.***Historical: Increase of 1.2+0.2 mm/yr from 1901 to 1990 and 3.0+0.7 mm/yr from 1993 to 2010 (Hay et al. 2015). Associated with this is increased energy delivery to the shore in the lower Bay from mid- to late-century (Varnell 2014) and increased nuisance flooding hours in Annapolis from a few hours/year prior to 1940 to more than 200 hours/year (Sweet et al. 2014). There has been an increase in nuisance flooding throughout the lower Bay in the last several decades (Sweet et al. 2014).* *Projected: Projections include increases of between 0.3 and 1.3 m, between 0.7 and 1.7 m, and between 0.7 and 1.6 m (Walsh et al. 2014; Boesch et al. 2013; Najjar et al. 2010, respectively). One half of SLR may be due to land subsidence in the southern Chesapeake; half of that subsidence may be due to aquifer compaction (Eggleston and Pope 2013). A 1 m increase in sea level could increase salinity by 4 ppt in dry years in the James and Chickahominy Rivers (Rice et al. 2012). Also, salinity and stratification may increase throughout the Bay (Hong and Shen 2012).* | *Increased storm surges, more frequent coastal inundation, larger areas of inundation, greater rates of coastal erosion, increased saltwater intrusion* | *Tidal wetlands only: Saltwater intrusion into wetlands, acreage loss due to inadequate vertical accretion and/or lack of space for horizontal migration**SAV only: Shifted area with light penetration suitable for SAV growth, altered salinity regimes leading to community composition changes* |
| **Rainfall**  | **Rainfall has increased and is projected to increase during the winter and decrease during the summer in the Chesapeake Bay.** *Historical: 10% increase in average annual precipitation across Pennsylvania within the last 100 years (Shortle et al. 2015).**Projected: Precipitation will increase throughout the year in Pennsylvania (8% increase) and the surrounding areas in every season (RCP8.5 scenario); within Pennsylvania, precipitation will increase the most in the eastern area (Shortle et al. 2015). Winters are projected to be wetter (14% increase in precipitation) and autumns drier in Pennsylvania (Shortle et al. 2015). Regionally, winter precipitation is projected to increase and summer precipitation to decline (Kunkel et al. 2013). Precipitation amount is expected to increase in winter and spring, although with uncertainty as to how large the change will be (Najjar et al. 2010). Precipitation intensity is predicted to increase under the A1B scenario by the end of this century (Meehl et al. 2007). .* | *Potentially more precipitation over fewer days, seasonal increases and decreases in suspended sediment delivery to Bay, seasonally reduced water clarity* | *SAV only: Seasonally reduced SAV growth due to reduced water clarity**Tidal wetlands only: Erosion from heavy rain* |
| **Extremes: drought & heavy rain** | **Droughts during the summer and heavy rain are predicted to become more frequent in the Chesapeake Bay.***Historical: Droughts have become less frequent and very wet years become more frequent in Pennsylvania (Shortle et al. 2015).**Projected: Storms with >150% of the current mean precipitation are predicted to increase in frequency for the Southeastern Piedmont and Lower Susquehanna regions of Pennsylvania (RCP2.6 statistically downscaled) (Shortle et al. 2015). Droughts between 1 and 3 months long are predicted to increase by 24-79% by 2070-2099 (compared to 1961-1990) under B1 and A1F1 scenarios; longer droughts are predicted to become even more common (Hayhoe et al. 2007).*  | *Potentially more droughts and extreme events, seasonal increases and decreases in suspended sediment delivery to Bay, increased saltwater intrusion* | *SAV only: Drought could cause osmotic stress in SAV by increasing salinity**Tidal wetlands only: Erosion from heavy rain* |
| **Ocean pH (SAV only)** | **Ocean acidity has increased and is projected to continue to increase.***Historical: pH has declined across the surface ocean by 0.1 units (Orr et al. 2005)**Projected: pH could decline by 0.5 units under the A2 emissions scenario by 2100 (Orr et al. 2015).*  | *Less available carbonate to form shells (shellfish, diatoms)* | *Reduced calcification by marine organisms**SAV only: increased CO2 concentration could aid SAV restoration if water clarity is sufficiently high but could also alter community composition due to different responses to CO2 and bicarbonate concentrations* |
| **Streamflow** | **While streamflow has become more extreme over time, projections include both increases and decreases, although winter and spring streamflow are likely to increase.***Historical: Low and high flows have increased since the 1930s (Groisman et al. 2001, 2004; Rice and Hirsch 2012; Armstrong and Collins 2014).**Projected: Small increases are possible in a variety of streamflow measures in the Susquehanna basin (A2 emissions scenario) (Johnson et al. 2012; U.S. EPA 2013) but streamflow projections elsewhere range from -40% to +30% under a doubling of atmospheric CO2 (Najjar et al. 2009). Streamflow may particularly increase in the Susquehanna between January and May, which could lead to an increase in summer stratification in the Bay (Najjar et al. 2010).* | *Decreased salinity during the winter and spring, seasonal increases and decreases in suspended sediment delivery to Bay, increased hypoxic area if streamflow increases* | *SAV only: Low flows could cause osmotic stress in SAV by increasing salinity, reduced water quality from seasonally increased sediment delivery**Tidal wetlands only: Altered volume and timing of delivery of suspended sediment necessary for soil accretion* |
| **Runoff and soil moisture (non-tidal wetlands only)** | **Runoff will increase in eastern Pennsylvania and soil moisture will increase in northern Pennsylvania and decrease in southern Pennsylvania.***Historical: N/A**Projected: Runoff will increase 15-20% in eastern Pennsylvania (Shortle et al. 2015). Soil moisture will increase in northern Pennsylvania and decrease in southern Pennsylvania and south of its border (Shortle et al. 2015).* | *Altered resource availability for wetlands, seasonal increases and decreases in suspended sediment delivery to Bay* | *Non-tidal wetlands only: Suitable habitat area will shift* |
| **Depth-to-groundwater (non-tidal wetlands only)** | **Depth-to-groundwater is not projected to change averaged across the whole year but is projected to increase during summers and decrease during winters, with variation by ecoregion and hydrogeomorphic group in Pennsylvania.** *Historical: N/A**Projected: Across the year, seven sample watersheds in Pennsylvania are projected to have approximately the same depth-to-groundwater in 2046-2065 as they did in 1979-1998. However, depth-to-groundwater is predicted to increase during the summer and decrease during the winter in those same watersheds, covering four ecoregions. The majority of wetland acreage in agricultural land is predicted to have the same or decreased depth-to-groundwater (Shortle et al. 2015).*  | *Altered resource availability for wetlands* | *Non-tidal wetlands only: Suitable habitat area will shift* |
| **Sediment and nutrient loads** | **Sediment and nutrient loads will depend on specific changes in temperature, precipitation, land use, and more but likely increase during the winter and spring.** *Historical: Concentrations of nitrogen and phosphorus generally declined in the largest Bay watersheds between 1985 and 2013 and sediment declined in the Potomac (Langland et al. 2012; Blomquist et al. 2014).* *Projected: Small increases are possible by mid-century in the Susquehanna basin (A2 emissions scenario: 12%, 13% and 49% median values for sediment, nitrogen, and phosphorus, respectively) (Johnson et al. 2012; U.S. EPA 2013). Nitrogen could increase by 17% by 2030 and 65% by 2095 in the Susquehanna (Howarth et al. 2006), although increased temperature could also decrease nitrogen loads by 20% (Schaefer and Alber 2007). In the Western Patuxent, nitrogen loads could decrease by 3% for a 1 °C increase and increase by 5% for a 5% precipitation increase. If precipitation intensity increases, sediment and phosphorus loads are likely to increase across the Bay (Najjar et al. 2010).*  | *Greater nutrient availability during winter and spring, increased seasonal sedimentation* | *Increased seasonal planktonic production/chlorophyll* a *concentration**SAV only: Reduced suitable habitat due to decreased water quality, increased epiphytic growth**Tidal wetlands only: Altered volume and timing of delivery of suspended sediment necessary for soil accretion* |
| **Hurricanes/ Severe storms** | **Hurricanes have become more intense and that may continue into the future.***Historical: Likely increased since the early 1980s, although the contribution of humans to that increase is unknown (Walsh et al. 2014).* *Projected: Hurricane intensity and rainfall rates may increase (Walsh et al. 2014). However, there is great uncertainty in hurricane projections at the regional scale (Najjar et al. 2010).*  | *Potentially more intense, possible change in tracks, altered Bay stratification* | *Increased damages to human community resources, altered plankton bloom dynamics**SAV only: physical destruction of SAV**Tidal wetlands only: Physical destruction of tidal wetlands, erosion of wetlands* |
| **OBSERVATIONS OF PAST AND PRESENT IMPACTS: Based on historical trends, what climate events are most frequent, and which have the greatest impacts? What changes to the normal seasons is the community noticing, and what are the impacts of those changes that most concern the community? Where are these changes or hazards occurring?** (Use Historical Timeline, Community Map.) ***SAV:*** *Water quality has been a persistent concern.* ***Tidal wetlands:*** *Extreme weather events have been a persistent concern.*  |
| **FUTURE: Based on the community’s past experience and the current situation, which of the projected climate threats and impacts most concern your community, and why?** (Use available scientific projections, the indicators of a changing climate, and observations from the past and present.) ***SAV:*** *Most concerned with the impacts of runoff and streamflow on water clarity and quality because those have demonstrable effects on SAV health and survival. Increase in frequency of powerful storms may become more significant.* ***Tidal wetlands:*** *Most concerned with sea level rise and altered hydrology. Increase in frequency of powerful storms may become more significant.* |

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| **Step 2: Assess Climate Impacts & Vulnerabilities: SAV** |
| **Target Resource:** *SAV* | **Condition and Trend Rating** |
| **Condition and Trends:** *SAVs declined historically but are currently in fair condition. They are sensitive to light limitation, poor water quality, and heat stress. Total SAV acreage not currently showing distinct trend, though some more local areas showing some natural recovery, presumably due to improving water quality and clarity.* | ***Fair*** ***SAV ACREAGE IS FLUCTUATING, WITH RECENT INCREASES*** |
| **Climate Threats** | **EXPOSURE** | **SENSITIVITY** | **POTENTIAL IMPACT****(Exposure + Sensitivity)** | **ADAPTIVE CAPACITY** | **VULNERABILITY****(Potential Impact + Adaptive Capacity)** |
| Increased water temperature, increased runoff, increased stream flow, increased frequency of severe storms, sea level rise | Very little protection from high levels of exposure to several climate threats, including sea level rise, increased storm intensity & frequency, and increased runoff with sediment/nutrient inputs. | High sensitivity to threats related to water clarity/quality and sea level rise, lower for storm frequency and water temperature (with the possible exception of *Zostera*)/ CO2 | SAV cannot avoid exposure and has mixed levels of sensitivity to different threats | No clear sign of SAV species adapting to light limitation or reduced water quality. SAV communities may adapt by altering community composition (some SAV species benefit while others are hurt), or at the community level through shoreward migration as habitats deepen due to SLR.  | SAV vulnerability to climate change is rated as high.  |
| **Exposure Rating** | **Sensitivity Rating** | **Potential Impact Rating** | **Adaptive Capacity Rating** | **Vulnerability Rating** |
| ***High*** | ***Medium*** | ***Medium HIGH*** | ***LOW*** | ***HIGH*** |
| **VulnerabilIty statement:** * **Condition and Trends:** SAV acreage has partially rebounded from its lowest values but acreage is fluctuating, albeit with steady increases in the last several years. Acreage has rebounded more in some locales and salinity zones.
* **Vulnerability:**SAV is highly vulnerable to climate change due to: sea level rise, increased runoff and stream flow (with concomitant changes in water quality and clarity), and increased severe storm frequency. Some SAV species are vulnerable to warmer water, while others may benefit from it.
* **Resource Dependency:**SAV in the Chesapeake Bay improves water quality, supports fisheries, provides wildlife habitat, oxygenates water, and reduces erosion.
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| **Step 2: Assess Climate Impacts & Vulnerabilities: Black duck habitat/wetlands** |
| **Target Resource:** *Black duck habitat/wetlands*  | **Condition and Trend Rating** |
| **Condition and Trends:** *Black duck habitat/wetlands declining due to habitat loss and degradation, shoreline disturbances, and climate change impacts (flooding, salt marsh migration/salinity changes, large storm events, sea level rise).* | ***🡫 trend for black duck HABITAT/WETLANDS*** |
| **Climate Threats** | **EXPOSURE** | **SENSITIVITY** | **POTENTIAL IMPACT****(Exposure + Sensitivity)** | **ADAPTIVE CAPACITY** | **VULNERABILITY****(Potential Impact + Adaptive Capacity)** |
| Altered hydrology, increased frequency of severe storms, more frequent droughts, sea level rise and warmer water temperatures (for tidal wetlands) | Very little protection from high levels of exposure to several climate threats, including altered hydrology and precipitation patterns and sea level rise.  | Black duck habitat and food availability is generally highly sensitive to predicted climate change stressors. | Potential climate change impact on black ducks is high due to high exposure and high sensitivity.  | Given space to move inland, tidal wetlands may be able to stay ahead of sea level rise, at least in some areas. Little evidence that wetlands will be to adapt to altered hydrology, although species composition changes are likely.  | Black duck habitat/wetlands vulnerability to climate change is rated as high.  |
| **Exposure Rating** | **Sensitivity Rating** | **Potential Impact Rating** | **Adaptive Capacity Rating** | **Vulnerability Rating** |
| ***High*** | ***HIGH*** | ***HIGH*** | ***LOW*** | ***HIGH*** |
| **VulnerabilIty statement:** * **Condition and Trends:** Black duck habitat/wetlands acreage is lower than historical levels.
* **Vulnerability:** Black duck habitat/wetlands is highly vulnerable to sea level rise due to altered hydrology, increased frequency of severe storms, increased frequency of droughts, and sea level rise and warmer water temperatures (for tidal wetlands).
* **Resource Dependency:**Black ducks rely on tidal and non-tidal wetlands for a variety of habitat needs, including for breeding, feeding, and migrating.
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