# Integrating Climate Change into Water Management Design

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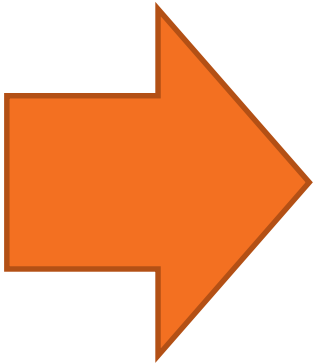
# Outline – What is this talk about?

- Introduction
- Conceptual Methodology
  - Sources
  - Baseline Models
  - Historical Info
  - Design Value
- Discussion

# Introduction

- General consensus that:
  - Climate change is occurring
  - Engineering design should consider climate change
- No consensus on:
  - Which climate change prediction methods is best
  - How to consider climate change in water management design



- Description of SRK's Standardized Procedure for Climate Change Integration into Water Management Design.
- Combining Climate Change models with historical information to determine change values used in engineering design.

# Conceptual Methodology - Sources

- Information is captured from:
  - First Assessment Report 1990 (FAR)
  - Second Assessment Report 1995 (SAR)
  - Third Assessment Report 2001 (TAR)
  - Fourth Assessment Report 2007 (AR4)
  - Fifth Assessment Report 2013 (AR5)
- No individual model or scenario is superior over another
- More recent Assessment Report models are not more reliable

# Conceptual Methodology - Sources

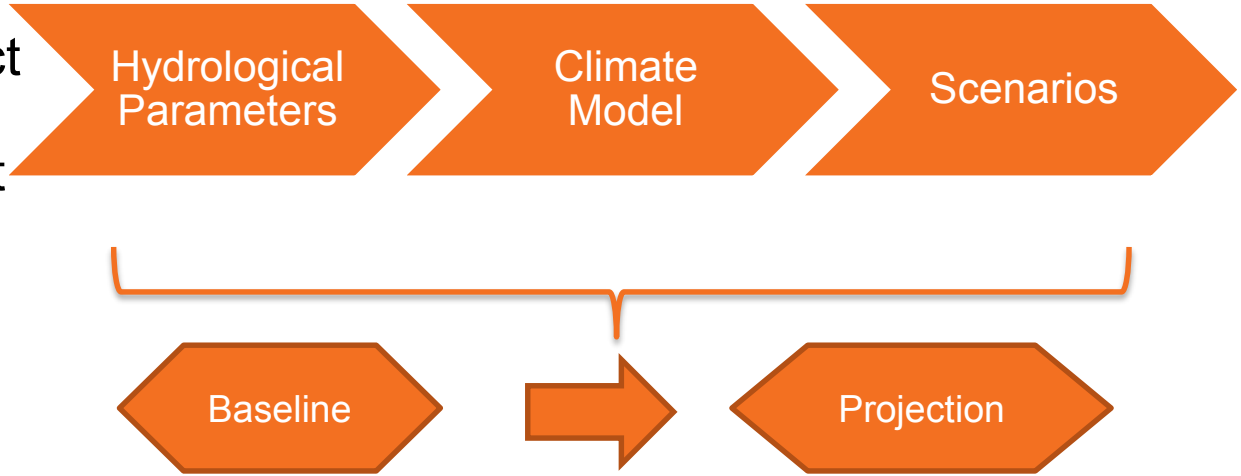
- Information provided by Environment and Climate Change Canada
- Used as hub for worldwide information.

| Variable | Base Variable | Details |
|---|---|---|
| Air Temperature | Temperature | Mean, mean maximum, mean minimum, and extreme range at 2 m above the ground surface |
| Heat Wave Duration Index | Temperature | Maximum period >5 consecutive days with $T_{max}$ >5°C above baseline $T_{max}$ normal |
| Frost Days | Temperature | Total number of days with absolute minimum temperature <0°C |
| Growing Season Length | Temperature | $T_{mean}$ >5°C for more than 5 days and $T_{mean}$ <5°C for more than 5 days |
| Air Temperature, Extreme Range | Temperature | Difference between the highest and lowest temperature in the same calendar year |
| Total Precipitation | Precipitation | Total rainfall and snowfall as water equivalent |
| Days with Rain >10 mm | Precipitation | Days with rain ≥10 mm/day |
| Simple Daily Intensity Index | Precipitation | Total annual precipitation / number of precipitation days ≥1 mm/day |
| Dry Days | Precipitation | Maximum number of consecutive days with precipitation <1 mm |
| Fraction of Total Annual Precipitation >95$^{th}$ Percentile | Precipitation | Annual precipitation >95$^{th}$ percentile |
| Wind Speed | Wind Speed | Mean, meridional, and zonal at 10 m above the ground surface |
| Solar Radiation | Radiation | Shortwave surface downwelling |
| Humidity | Humidity | Relative and specific humidity at 2 m above the ground surface |
| Sea Level Pressure | Air Pressure | Mean sea level pressure |

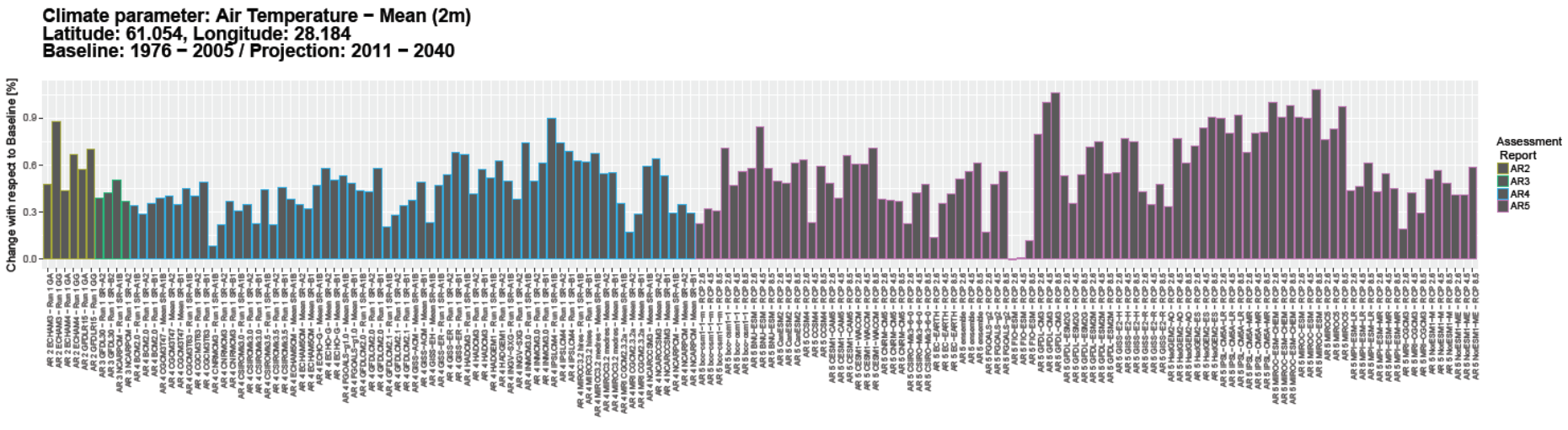
# Conceptual Methodology – Baseline Models

- Climate change projected with respect to set baseline condition spanning at least 30 years (1976-2005)

- Considers 3 projection periods
  - 2011-2040 (2020s)
  - 2041-2070 (2060s)
  - 2071-2100 (2080s)



# Conceptual Methodology – Baseline models




**Yearly Avg. between 1976 to 2005 (Baseline)**

Change with respect to baseline [%]

**Yearly Avg. between 2011 to 2040 (Projection)**

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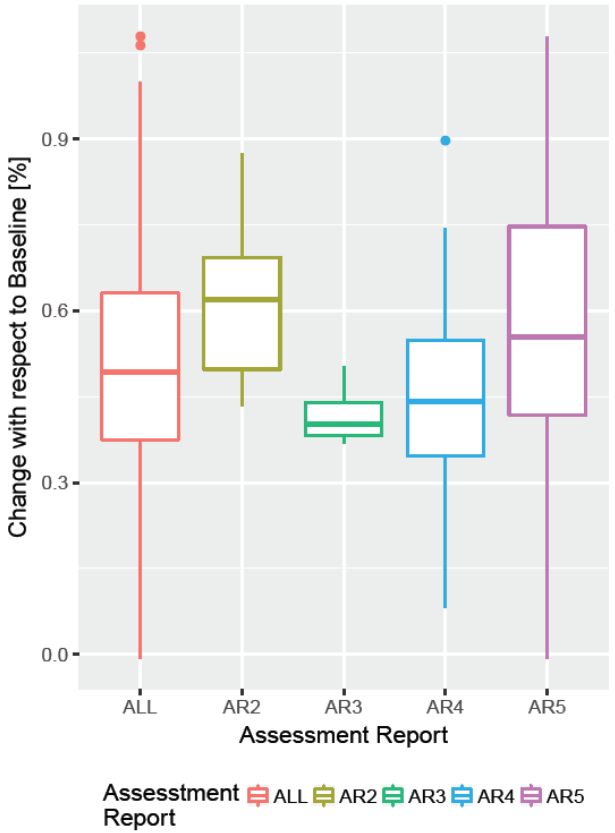
# Conceptual Methodology – Baseline models

- Same data presented as box-whisker plot
- Box centerline represents median value
- Upper and lower borders represent the third and first quartiles
- Whiskers span maximum and minimum values

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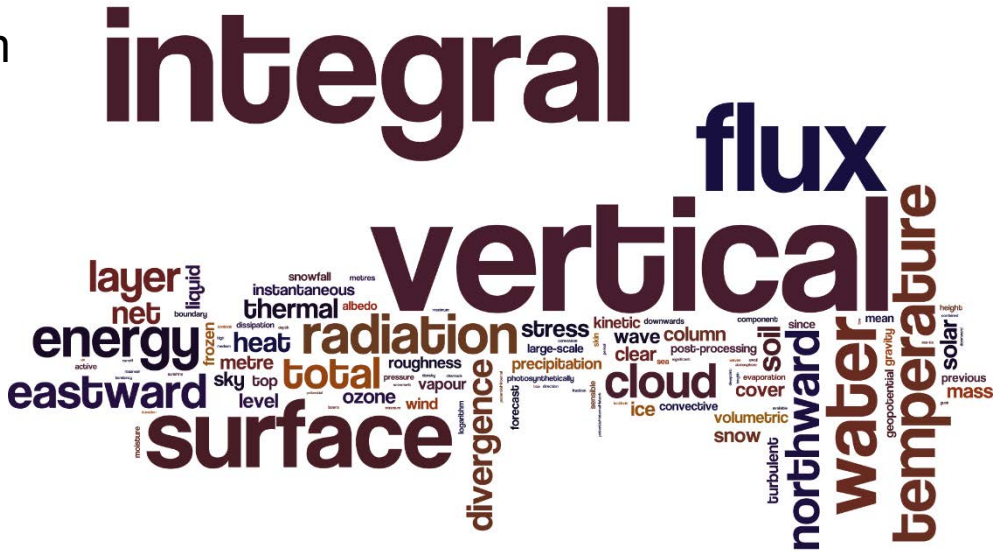
# Conceptual Methodology – Historical Info

- Reanalysis typically extends from ~1980 to present (2017), and covers the entire globe from the Earth's surface to well above the stratosphere.
- Sources of reanalysis are:
  - ERA-Interim
  - MERRA/MERRA-2
  - JRA-55
  - NCEP/NCAR

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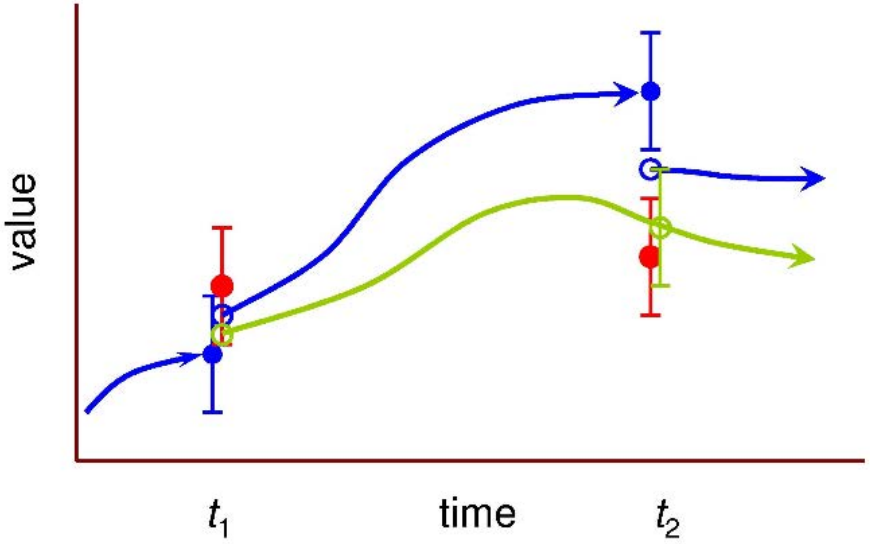
# Conceptual Methodology – Historical Info

- 3DVar vs 4DVar Assimilation
  - 4DVar assimilation is more representative of the measured values because forecast information is corrected within the respective time step.
  - One of the few state of the art with 4D-var assimilation is ERA-Interim (ECMWF), and then it was used in this review.

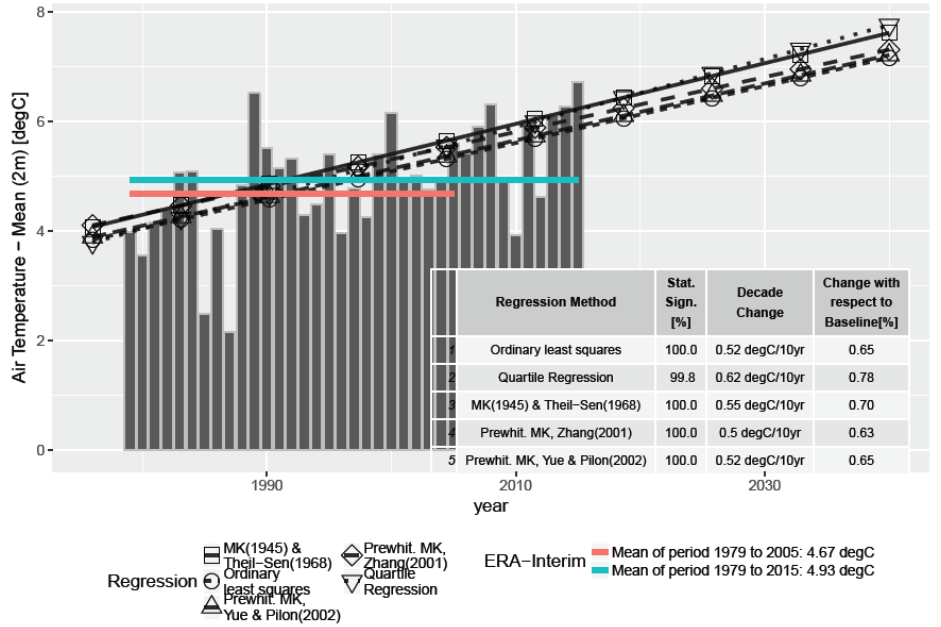



Comparison between measured data (red), 3DVar data assimilation (blue) and 4DVar data assimilation (green) (Kepert, 2009)

# Conceptual Methodology – Historical Info

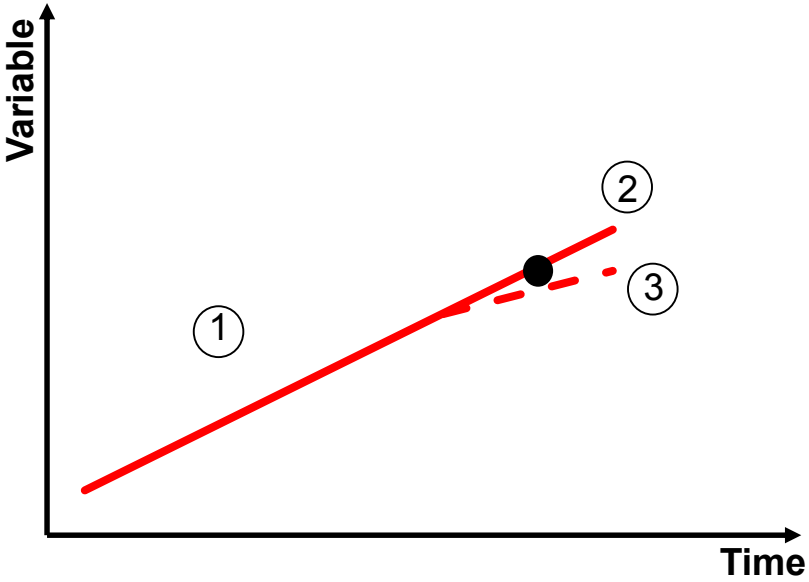
- ERA-Interim =>Trend analysis using five methodologies are implemented:
  - Ordinary Least Square
  - Quantile Regression
  - Mann-Kendall and Theil Sen
  - Zhang
  - Yue and Pilon

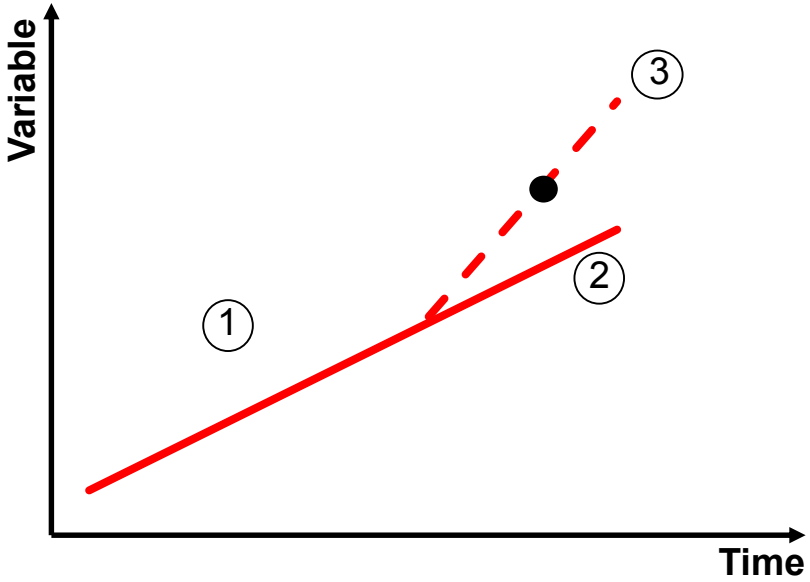
- Regression methods with more than 95% statistical significance are used (P-value < 0.05).




| Regression Method | Stat. Sign. [%] | Decade Change | Change with respect to Baseline[%] |
|---|---|---|---|
| Ordinary least squares | 100.0 | 0.52 degC/10yr | 0.65 |
| Quartile Regression | 99.8 | 0.62 degC/10yr | 0.78 |
| MK(1945) & Theil–Sen(1968) | 100.0 | 0.55 degC/10yr | 0.70 |
| Prewhit. MK, Zhang(2001) | 100.0 | 0.5 degC/10yr | 0.63 |
| Prewhit. MK, Yue & Pilon(2002) | 100.0 | 0.52 degC/10yr | 0.65 |

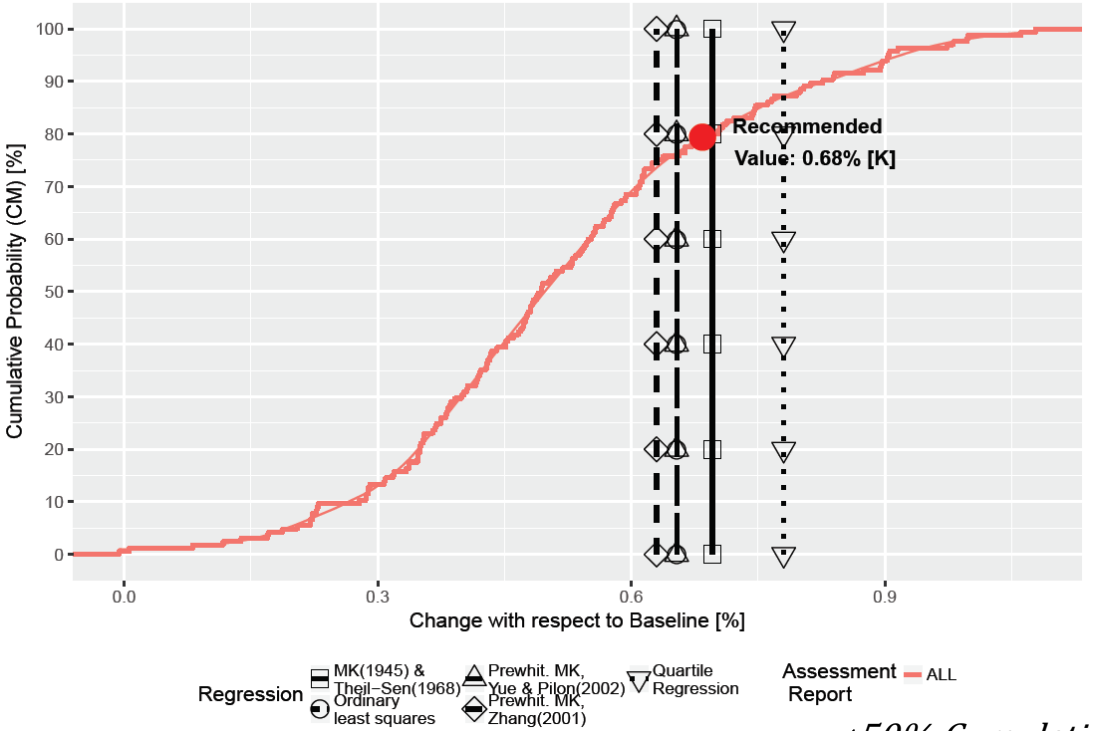
# Conceptual Methodology – Design value




Climate change trends from (1) historical data, (2) forecasted historical trend, (3) climate change models. Black dot represents climate change design value used

# Conceptual Methodology – Design value

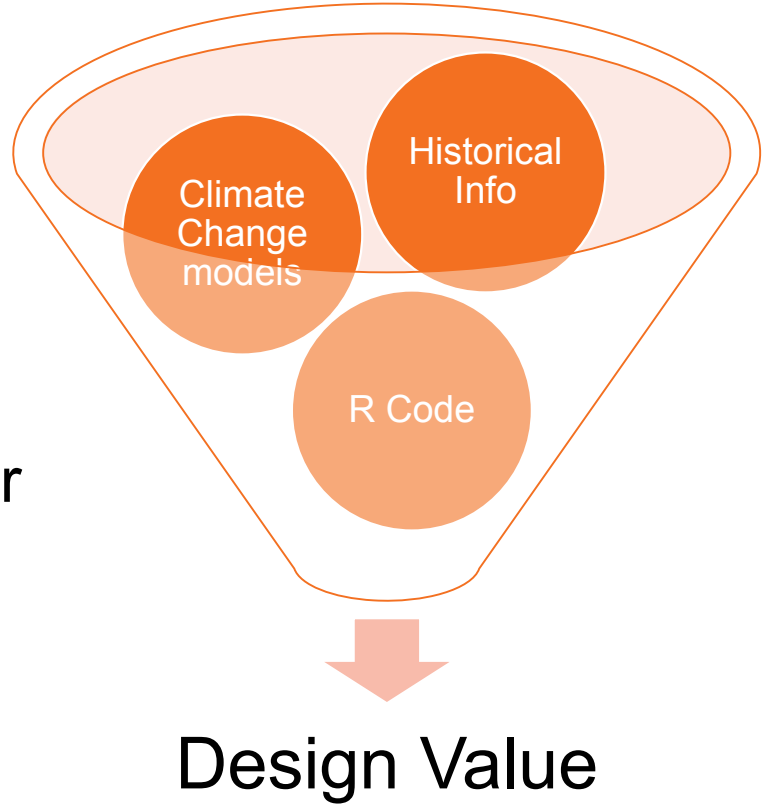



- +0.68% [K] => +1.9 °C

Climate Change *Design Value* = *Max.* $\left( \begin{matrix} 50\%\ Cumulative\ Probability, \\ Mean\{Regression_{P-value < 0.05}\} \end{matrix} \right)$

# Discussion

- This methodology combines historical information with climate change models to define one engineer design value.
- Solution can be useful to account for changes in water balances and civil structure design.



# Questions?

**Climate parameter: Air Temperature − Mean (2m)**
**Latitude: 61.054, Longitude: 28.184**
**Baseline: 1976 − 2005 / Projection: 2011 − 2040**