Estimating Future Costs of Alaska Public Infrastructure at Risk to Climate Change

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"The nation behaves well if it treats resources as assets which it must turn over to the next generation increased, and not impaired, in value."

-Theodore Roosevelt, 1910

"50 years ago I used to swear at my dog team. Today, I swear at my computer. [Climate] change is change and you must adjust to it. My generation survived a lot. It's been all uphill in the North since then. I have great confidence in your generation."

-Walt Parker, 2005

Research Objective

Question:

What *objective* insights can be made about the potential costs to Alaska public infrastructure from rapid climate change?

Answer:

ISER-UAA has built a policymaking tool to estimate the additional replacement costs to public infrastructure due to climate change. Our preliminary model runs show a plausible range of costs by infrastructure type and area. Under any scenario, what we can say is that aggregate costs will total at least several billion of today's dollars.

Presentation Outline

I. Discussion of Caveats

II. Historical Climate

III. Climate/Weather Impacts Infrastructure

IV. Introducing "ICICLE" Model

   A. Alaska Public Infrastructure Database

   B. Most Recent Projections of Future Climate

   C. Public Infrastructure Lifecycle Analysis

   D. Preliminary Results

V. Conclusion

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Caveat Emptor

I. Experimental Policymaking Tool

This model is in the early stages of development and all results presented today are preliminary.

II. ISER Alaska Infrastructure Database (APID)

This is the first time the APID has been put to use. The APID will be continuously revised at ISER's discretion.

III. Borough/Census Area-level Results

Borough/Census Area-level results only until the underlying assumptions and databases have been thoroughly vetted.

IV. Underlying Causes of Climate Change

No official ISER position on the underlying causes of climate change (anthropogenic vs. natural) will be made in this paper.

Caveat Emptor (cont.)

V. Interpretation of Uncertainty in Climate Projections

All models whether they are climate change models or economics models have inherent uncertainties that need to be discussed before interpretation.

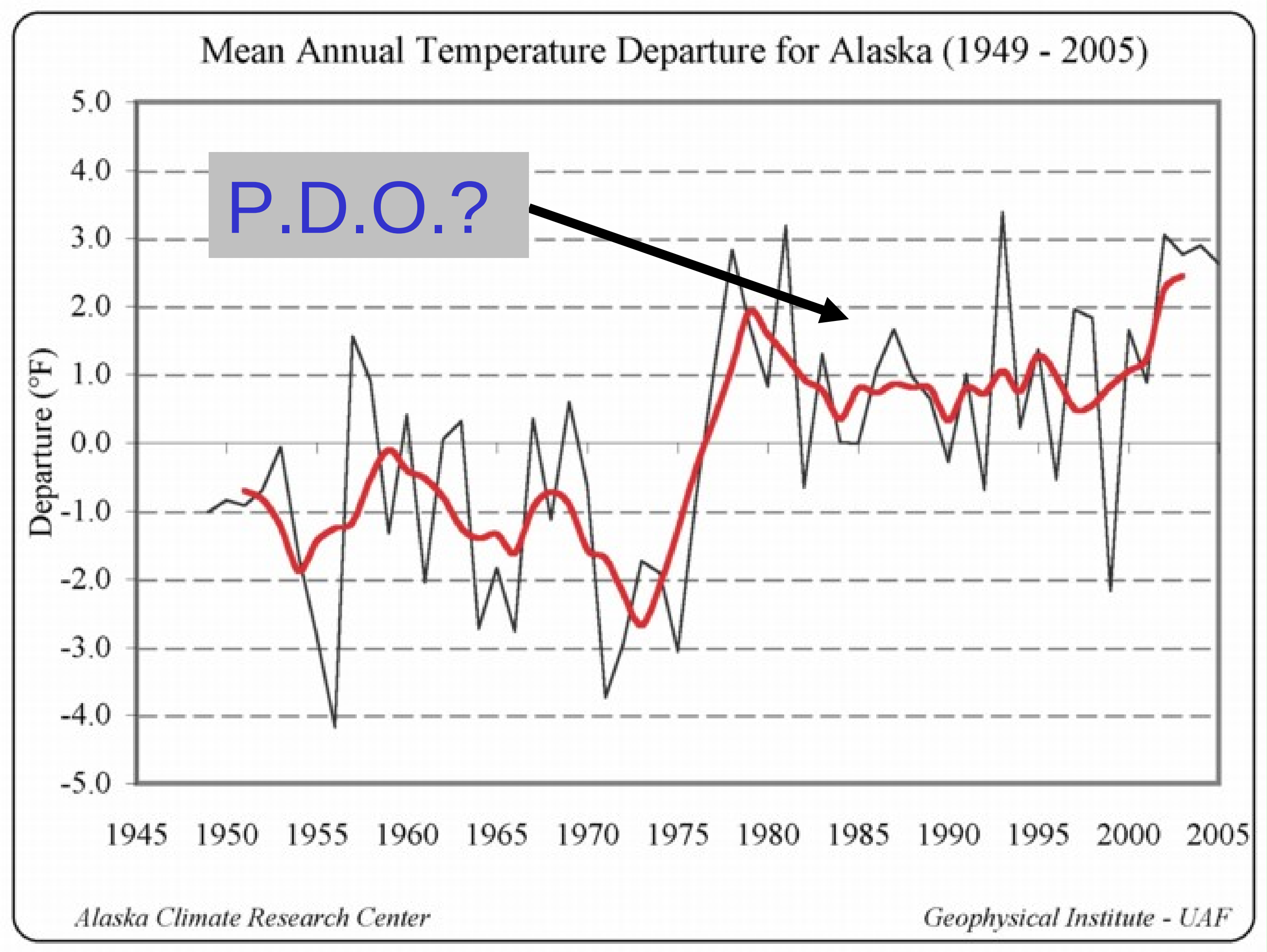
VI. Economic Activity and the Disconnect with Societal Well-being

In rural Alaska, subsistence and other traditional economies don't always adhere to Western measures of "progress".

VII. Estimates of Costs, Depreciation Rates, and Lifespans

Little information on actual, location-specific replacement costs. Rough estimates of average infrastructure replacement costs, depreciation rates, and useful lifespans were used in preliminary model runs.

Changes Underway…



Source: UAF, Geophysical Institute (2006)

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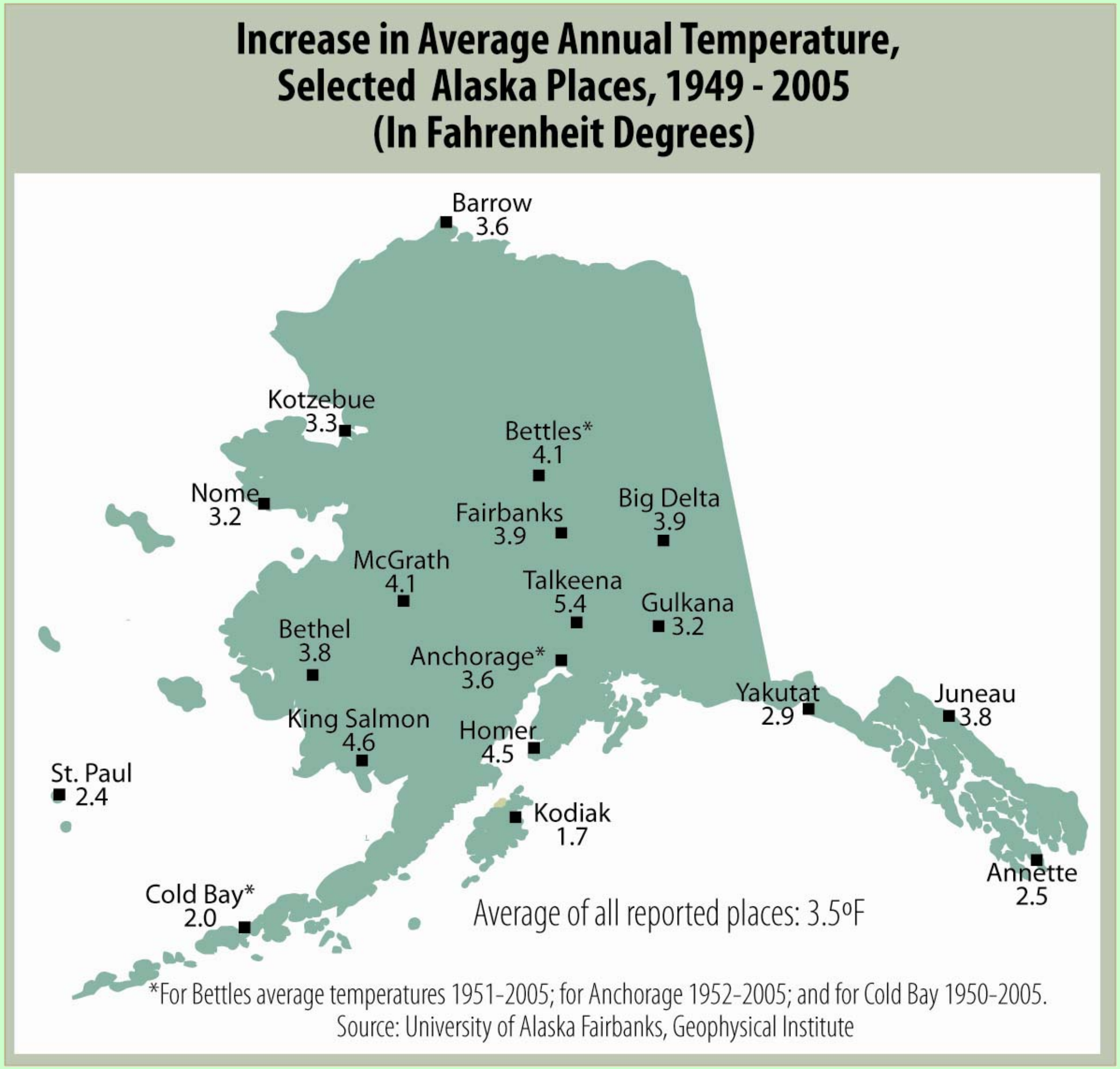
Changes Underway…



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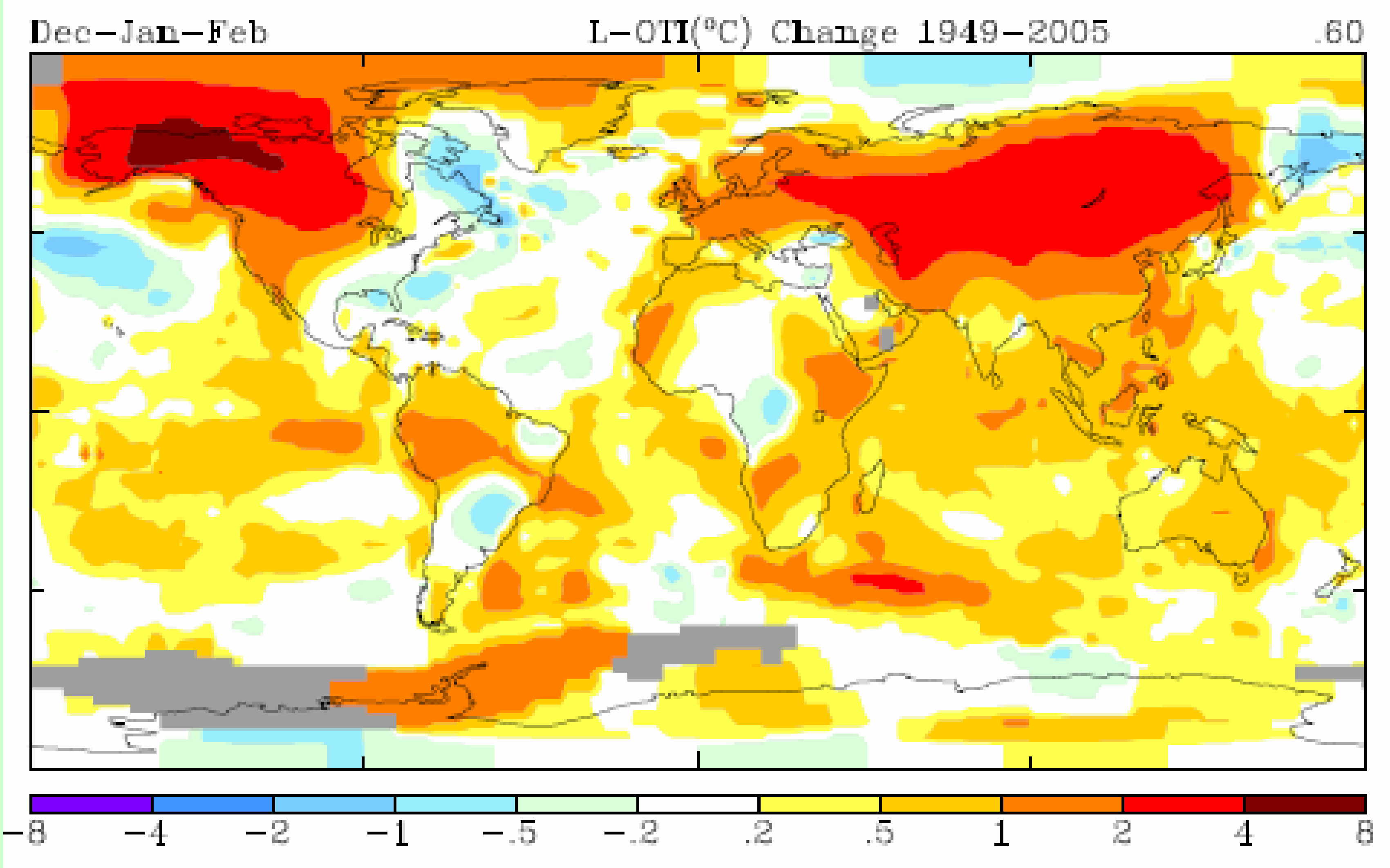

Source: NASA, GISS (2007)

Climate Change Impacts Public Infrastructure

1. *Thawing Permafrost*

Thawing permafrost causes roads and foundations to prematurely buckle.

2. *Local Sea-level Rise*

Sea-level rise directly damages adjacent built environment and accelerates erosion.

3. *Increased Coastal Erosion*

Increased storm activity/sea-level rise rapidly erodes exposed coastal communities.

4. *Increased Flooding*

Floods damage bridges, roads, landing strips, and water utility systems, etc.

5. *Increased Fire Activity*

Fires directly damage built structures including government buildings.

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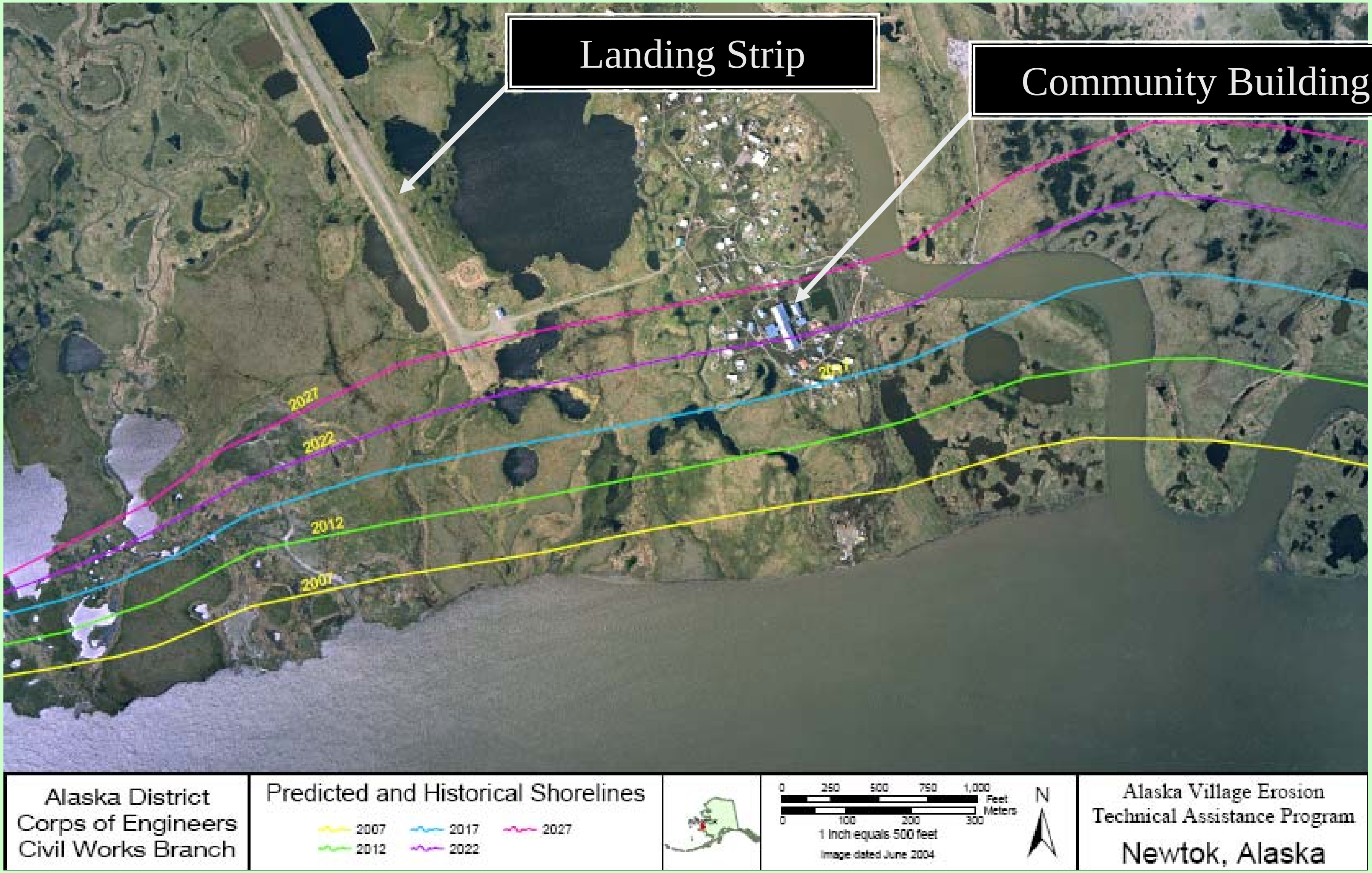
Example of Rapid Coastal Erosion Impacting the Built Environment



Steps to Estimating the Impact of Climate Change on Public Infrastructure

1. Construct public infrastructure database (APID).
2. Calculate PV of basecase replacement costs of infrastructure: 2030 & 2080.
3. Import high resolution climate projections (6 regions, temp. & precip.).
4. Import historical climate information (6 regions, temp. & precip.).
5. Produce probability distributions of projected climate by region.
6. Import infrastructure-climate depreciation matrix (UAA Engineering)
7. Repeatedly draw from distributions of projected climate (Monte-carlo simulation) by region.
8. Adjust useful lifespan of infrastructure based on drawn climate combination using depreciation matrix and prob. of extreme events.
9. Calculate PV of climate scenario replacement costs of infrastructure: 2030 & 2080.
10. Subtract PV of basecase costs from PV of climate scenario costs.
11. Output additional replacement costs due to climate change by community and infrastructure type with probabilities.

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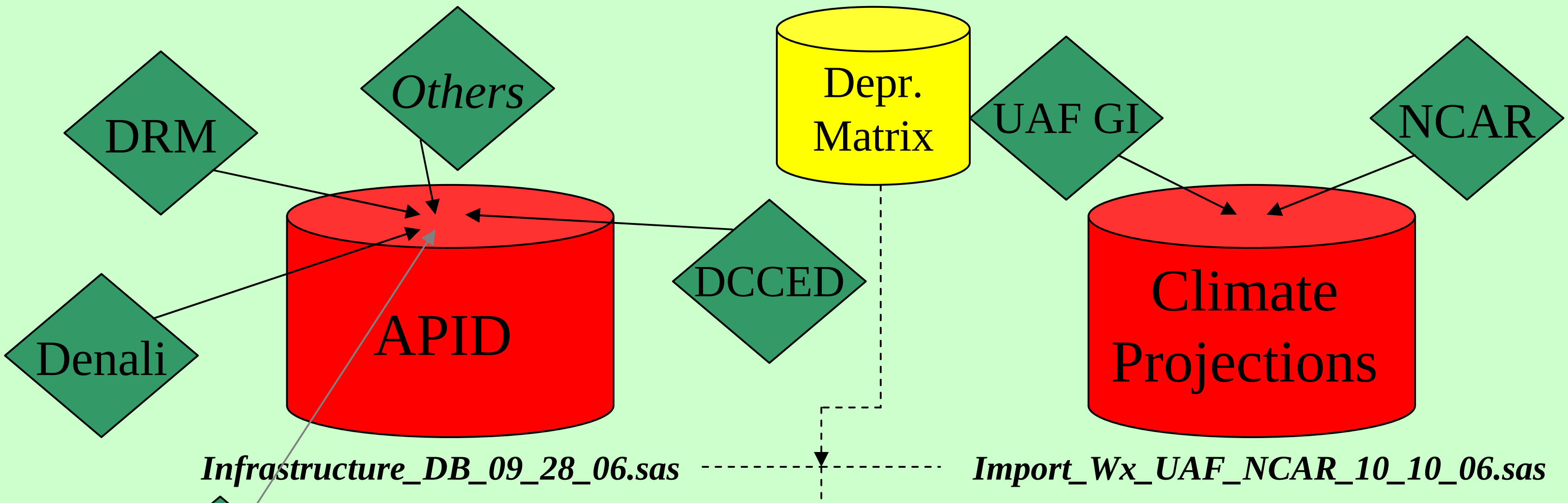
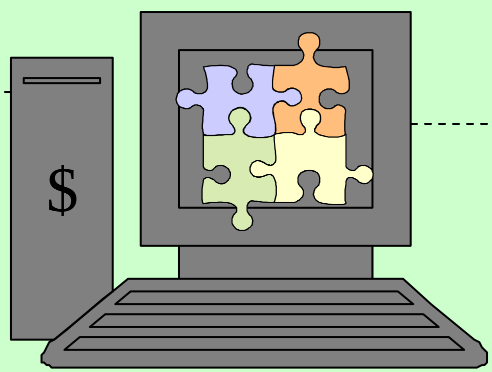
Flow Chart of Model Processes





Infrastructure Type		Replacement Cost	Units	Baseline Useful Life (years)
Agriculture		N/A	N/A	N/A
Airport	$	5,664,812	Whole	10
Bridges	$	10,000	Per foot	40
Courts	$	16,150,618	Whole	40
Defense	$	305,441	Whole	40
Emergency Services	$	467,110	Whole	20
Energy	$	31,570	Whole	30
Grid	$	100,000	Per mile	15
Harbor	$	162,050	Whole	30
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Sewer	$	30,000,000	Whole	20
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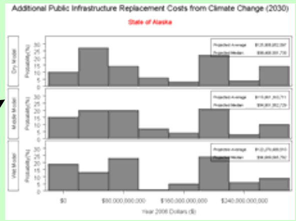
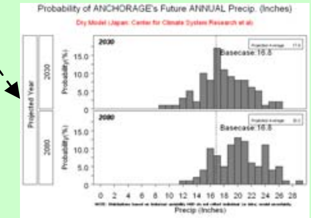
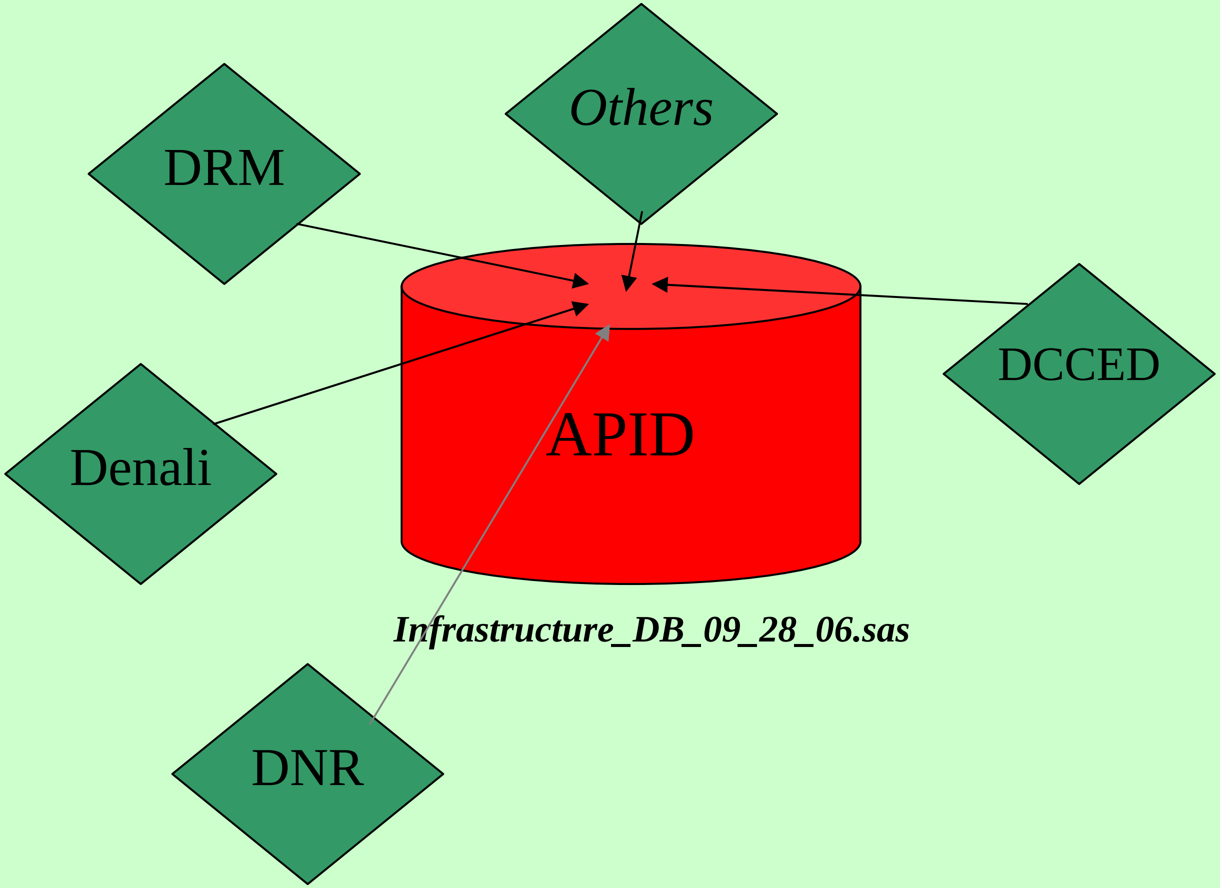
Tables





Graphs

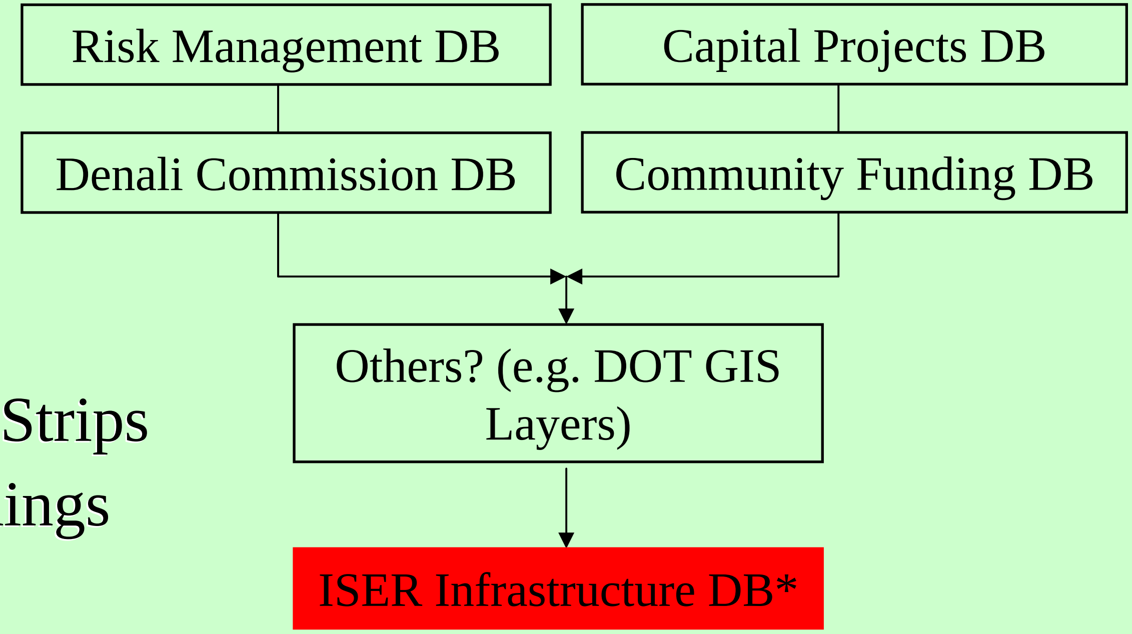
Construction of ISER APID



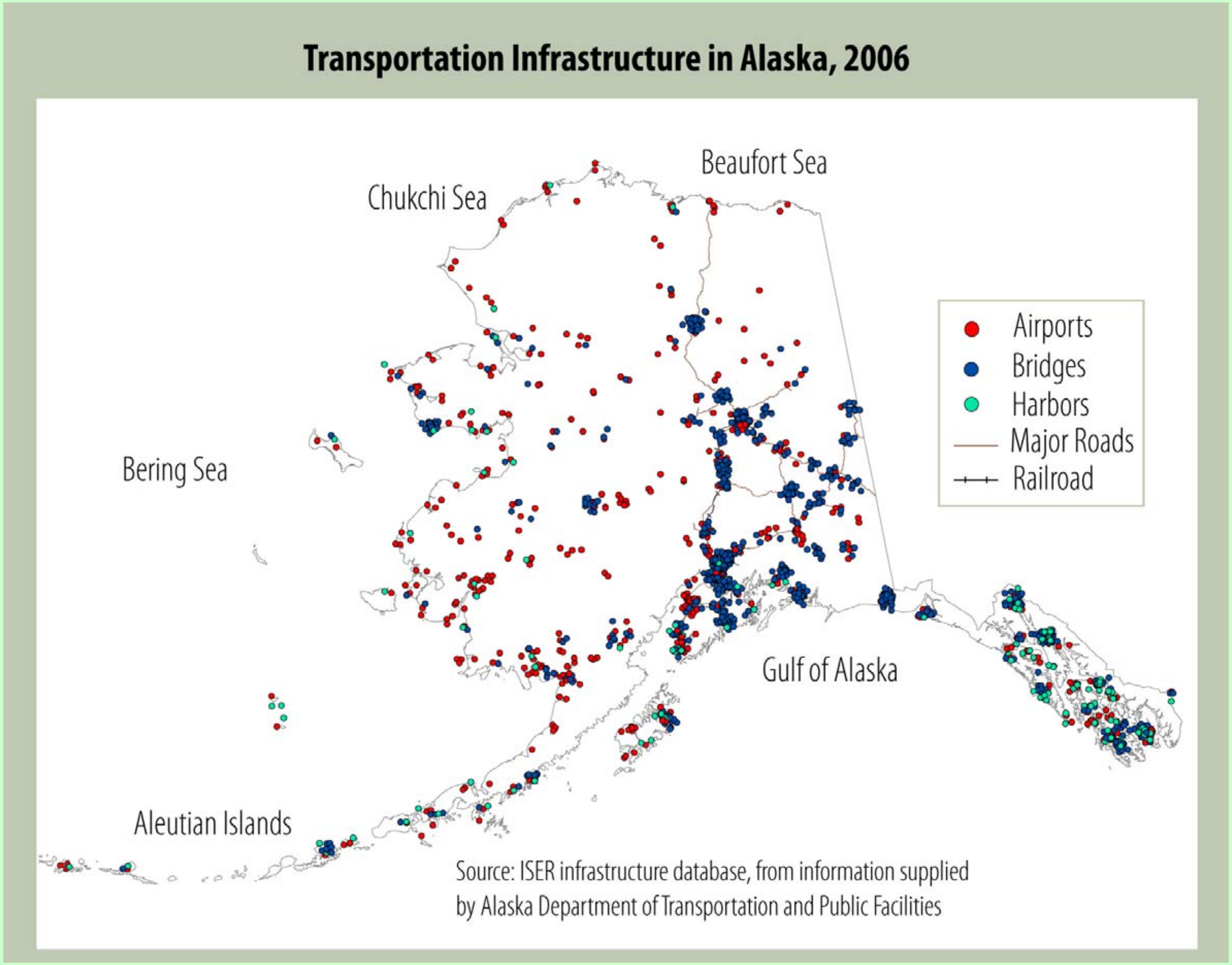
Current Research: ISER APID

Building Inventory (i.e. database) of Alaska Public Infrastructure including:

- Harbors
- Schools
- Roads
- Airports/Landing Strips
- Community Buildings
- Hospitals
- Telecommunications/Electric Systems
- Water/Wastewater Systems
- Bridges



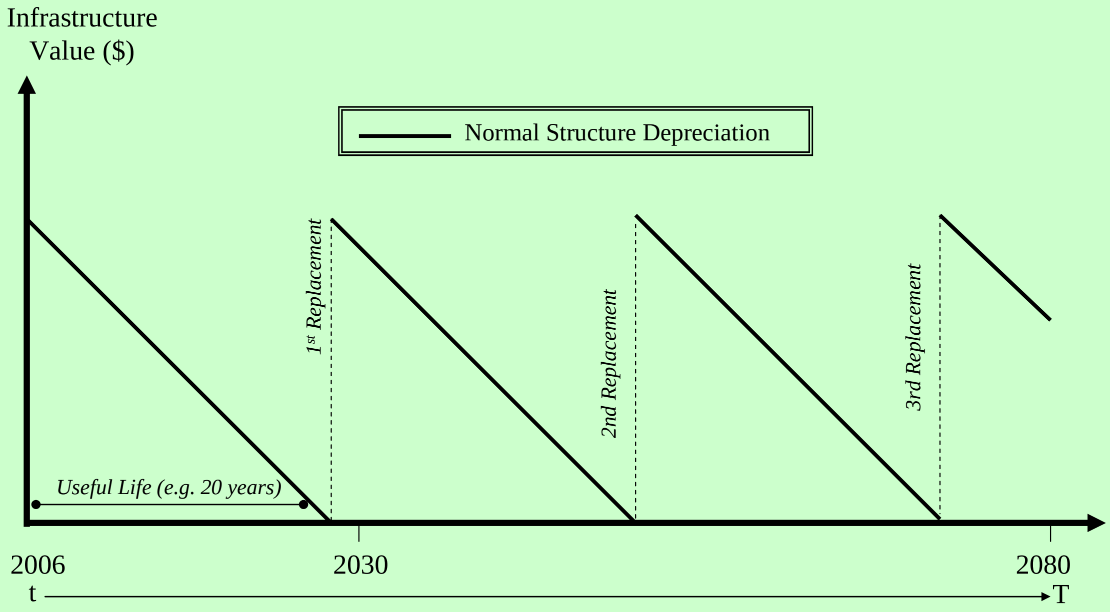
Mapping Alaska Infrastructure



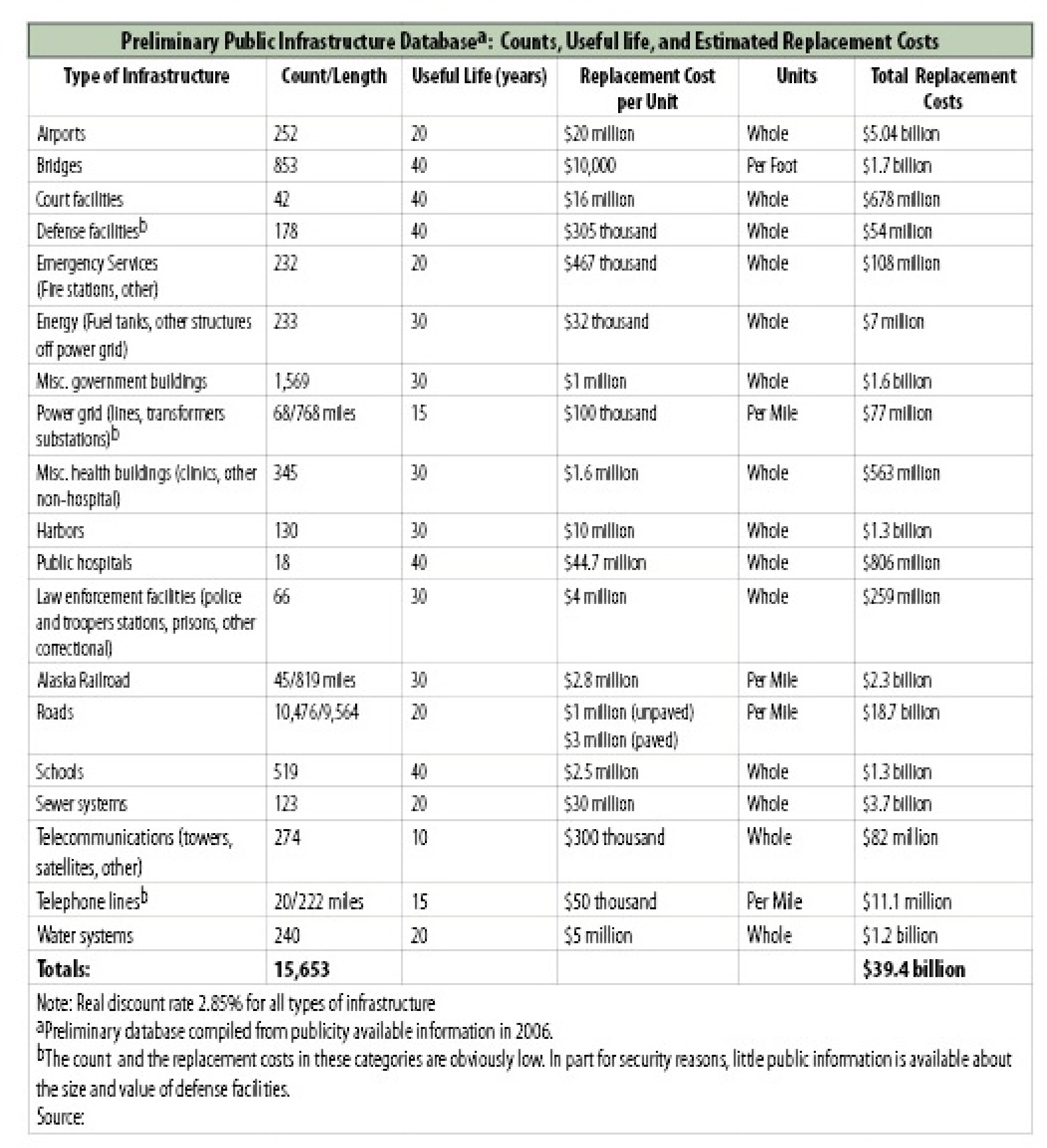
Calculating the Baseline Replacement Costs of Alaska Public Infrastructure

I. BASELINE: Depreciate infrastructure using standard financial techniques (e.g. straight line method) <u>and</u> average documented lifespans of various asset classes (bridges vs. schools, etc.).

II. Calculate present value of baseline scenario. (PV_{BASE})



Rough Approximations of Useful Life and Replacement Costs (Inputs)



Preliminary Public Infrastructure Database[a]: Counts, Useful life, and Estimated Replacement Costs					
Type of Infrastructure	Count/Length	Useful Life (years)	Replacement Cost per Unit	Units	Total Replacement Costs
Airports	252	20	$20 million	Whole	$5.04 billion
Bridges	853	40	$10,000	Per Foot	$1.7 billion
Court facilities	42	40	$16 million	Whole	$678 million
Defense facilities[b]	178	40	$305 thousand	Whole	$54 million
Emergency Services (Fire stations, other)	232	20	$467 thousand	Whole	$108 million
Energy (Fuel tanks, other structures off power grid)	233	30	$32 thousand	Whole	$7 million
Misc. government buildings	1,569	30	$1 million	Whole	$1.6 billion
Power grid (lines, transformers substations)[b]	68/768 miles	15	$100 thousand	Per Mile	$77 million
Misc. health buildings (clinics, other non-hospital)	345	30	$1.6 million	Whole	$563 million
Harbors	130	30	$10 million	Whole	$1.3 billion
Public hospitals	18	40	$44.7 million	Whole	$806 million
Law enforcement facilities (police and troopers stations, prisons, other correctional)	66	30	$4 million	Whole	$259 million
Alaska Railroad	45/819 miles	30	$2.8 million	Per Mile	$2.3 billion
Roads	10,476/9,564	20	$1 million (unpaved) $3 million (paved)	Per Mile	$18.7 billion
Schools	519	40	$2.5 million	Whole	$1.3 billion
Sewer systems	123	20	$30 million	Whole	$3.7 billion
Telecommunications (towers, satellites, other)	274	10	$300 thousand	Whole	$82 million
Telephone lines[b]	20/222 miles	15	$50 thousand	Per Mile	$11.1 million
Water systems	240	20	$5 million	Whole	$1.2 billion
Totals:	**15,653**				**$39.4 billion**

Note: Real discount rate 2.85% for all types of infrastructure
[a]Preliminary database compiled from publicity available information in 2006.
[b]The count and the replacement costs in these categories are obviously low. In part for security reasons, little public information is available about the size and value of defense facilities.
Source:

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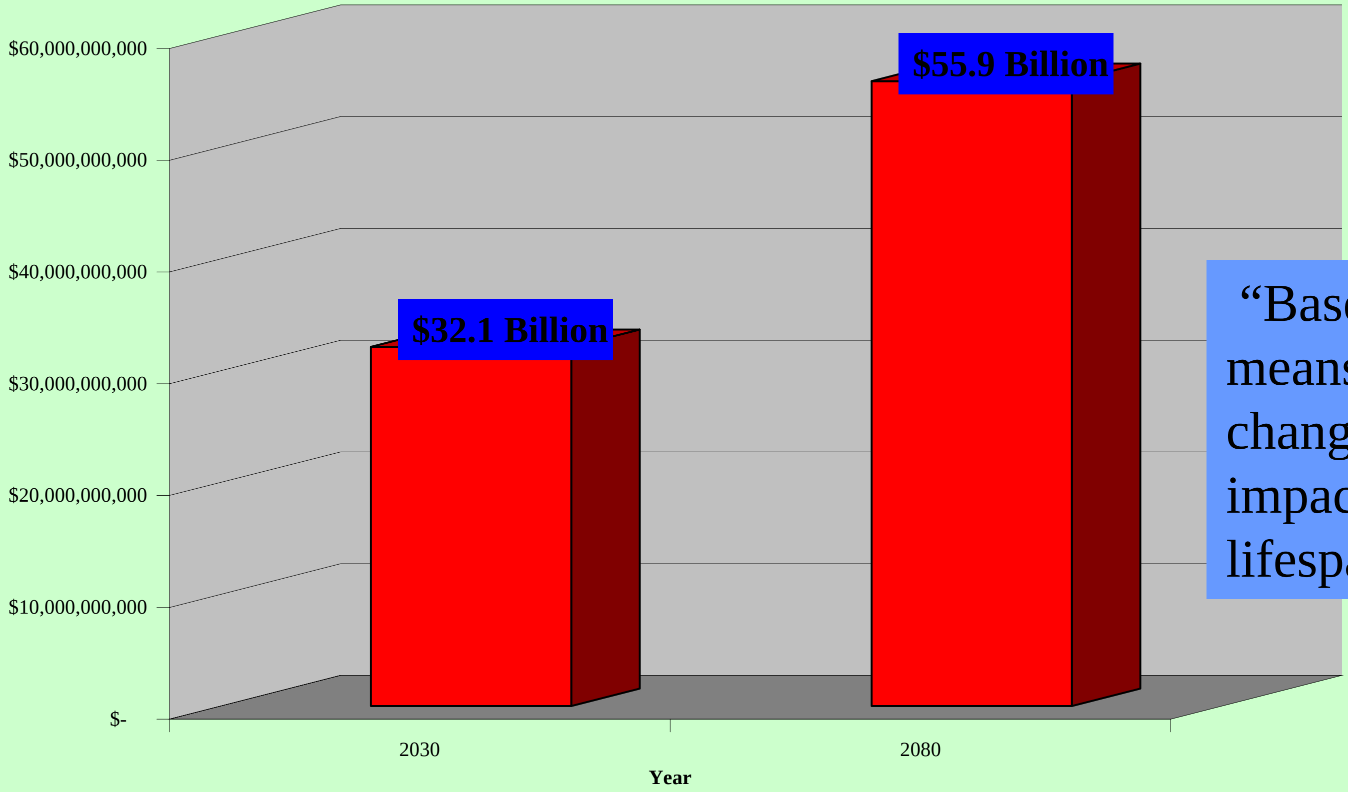
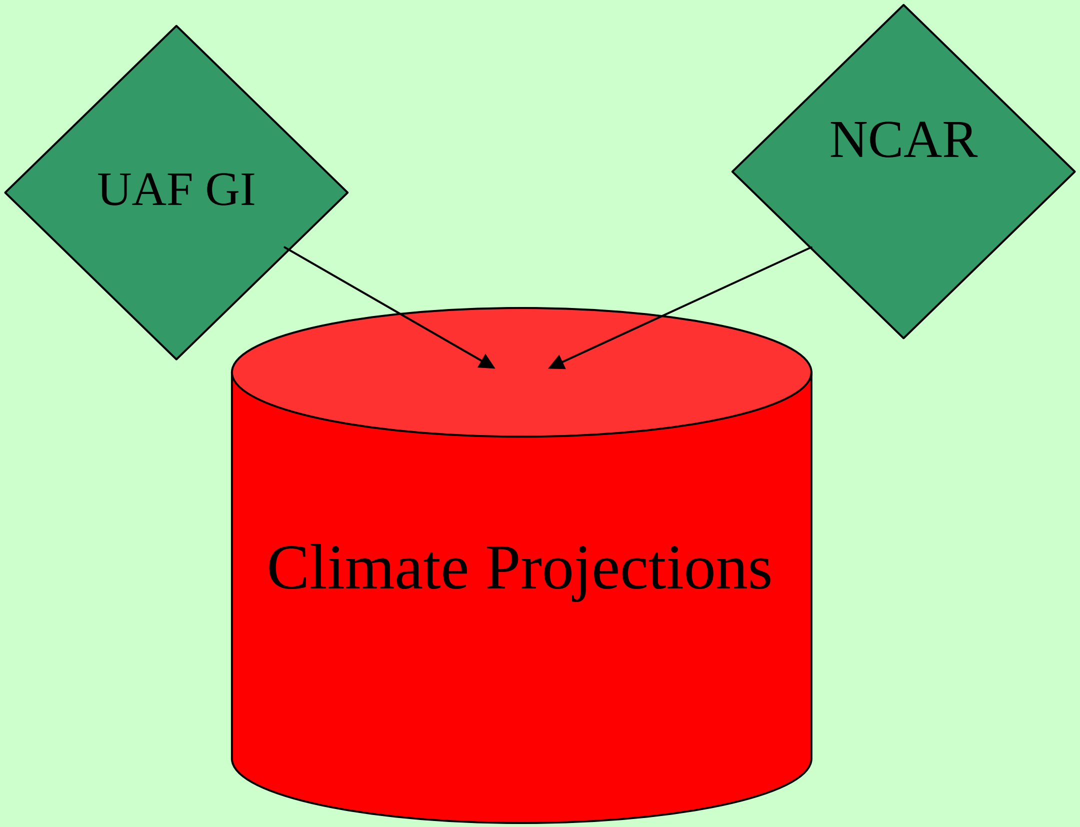
Base Case Replacement Costs for Alaska's Public Infrastructure



"Base Case" means <u>no</u> climate change effects impacting lifespan.

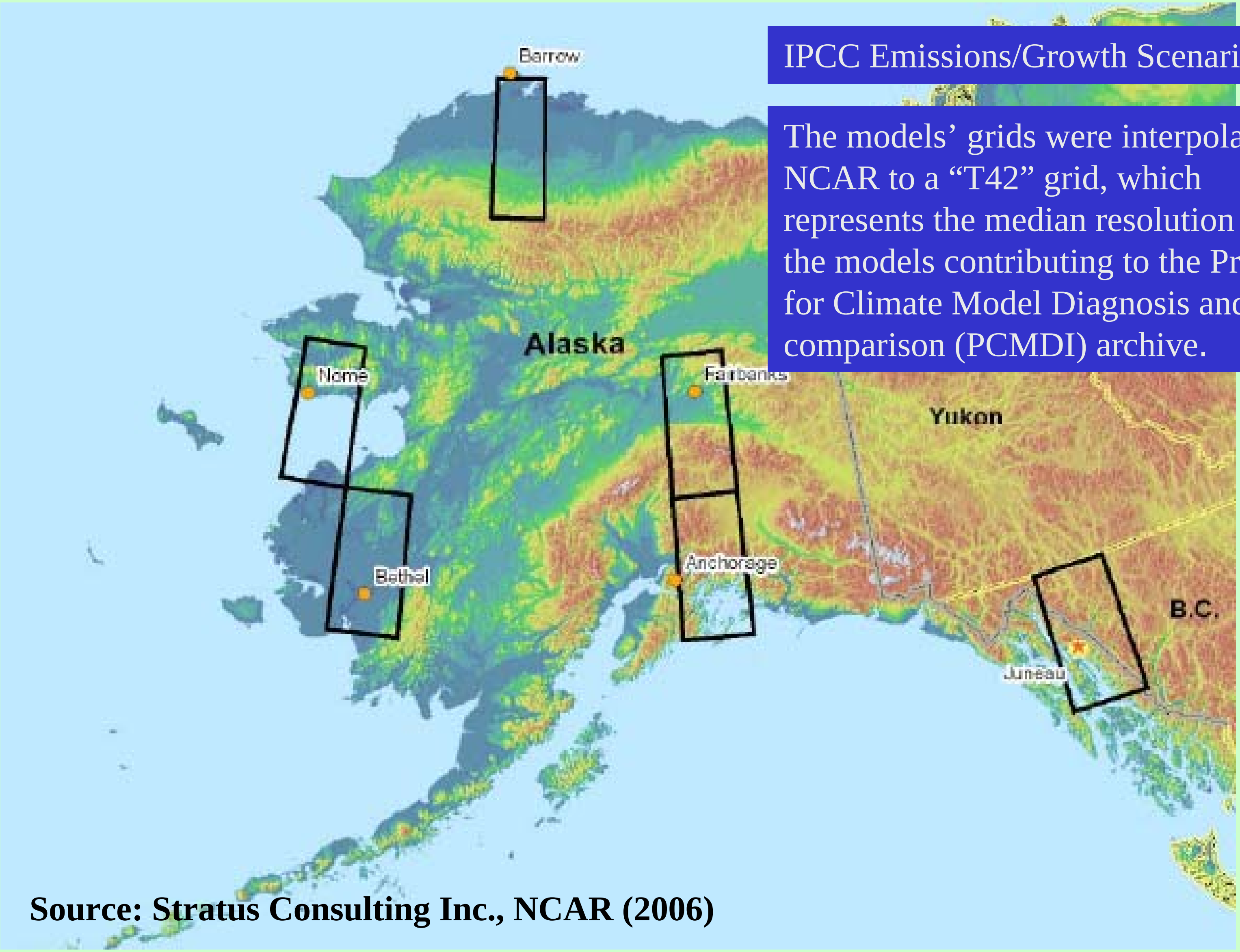
Source: ISER (2007)

Processing NCAR Climate Data



Import_Wx_UAF_NCAR_10_10_06.sas

NCAR/ISSE Alaska Climate Data



IPCC Emissions/Growth Scenario: A1B

The models' grids were interpolated by NCAR to a "T42" grid, which represents the median resolution among the models contributing to the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) archive.

Source: Stratus Consulting Inc., NCAR (2006)

High Resolution Climate Projections for Alaska

- NCAR provided ISER with output from 21 climate models from all over the world.
- Projections were made for: Anchorage, Barrow, Bethel, Fairbanks, Juneau, and Nome for the years 2030 and 2080.
- Model output included Monthly and Annual estimates of future precipitation and temperature.
- ISER was not provided individual model uncertainty.
- ISER used long-term historical temp./precip. measurements to proxy “natural variability” for our initial model runs.
- With help from experts at Stratus Consulting, ISER will present three representative climate models for Alaska:
    1. <u>Warm</u> Model (CSIRO, Australia)
    2. <u>Warmer</u> Model (NOAA GFDL0, U.S.)
    3. <u>Warmest</u> Model (MIROC-HIRES, Japan)

21 Regional Climate Projections

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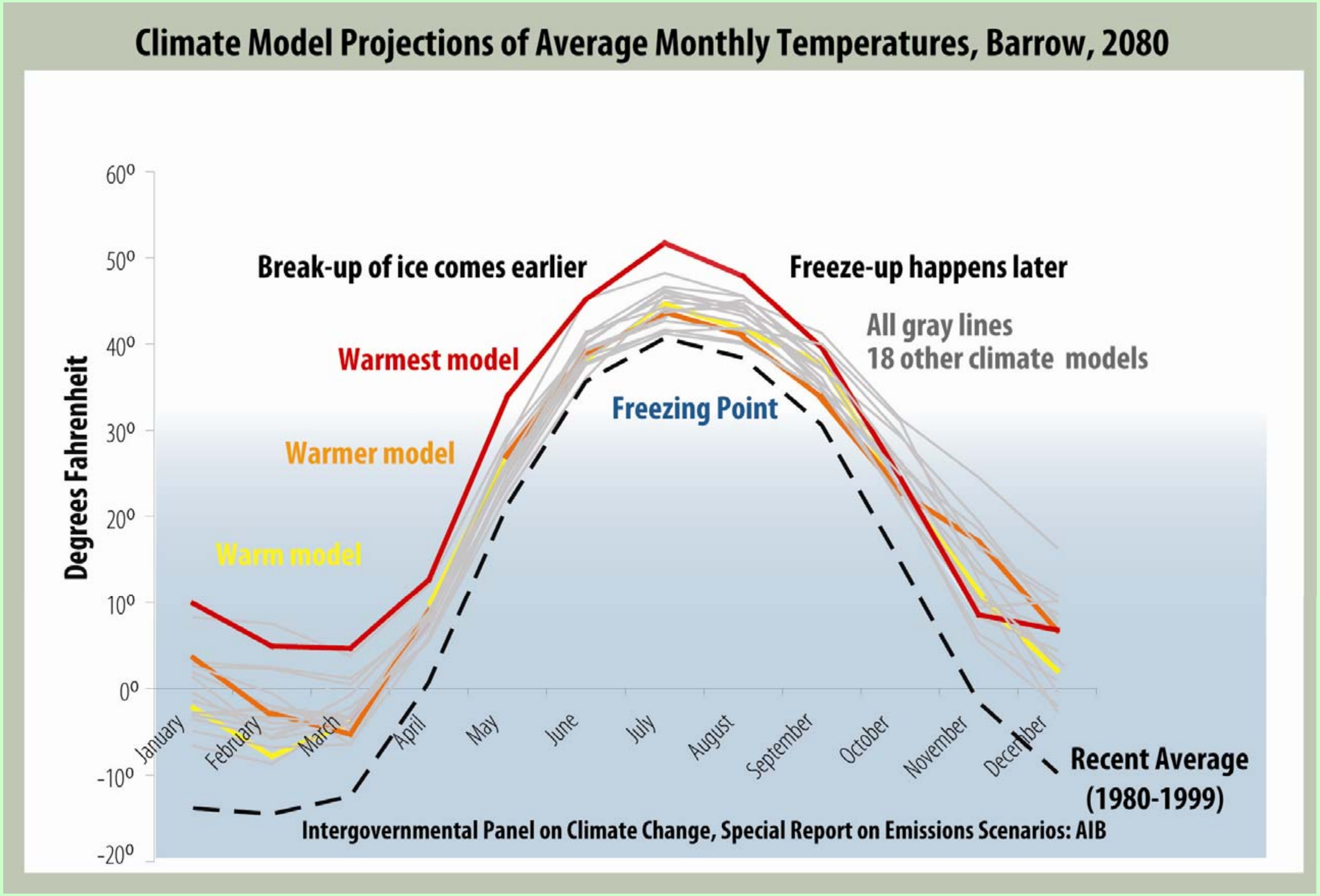

Source: Lawrence Livermore National Lab. (PCMDI) > NCAR/ISSE > UAA/ISER (2006)

Climate Projections with Probabilities*

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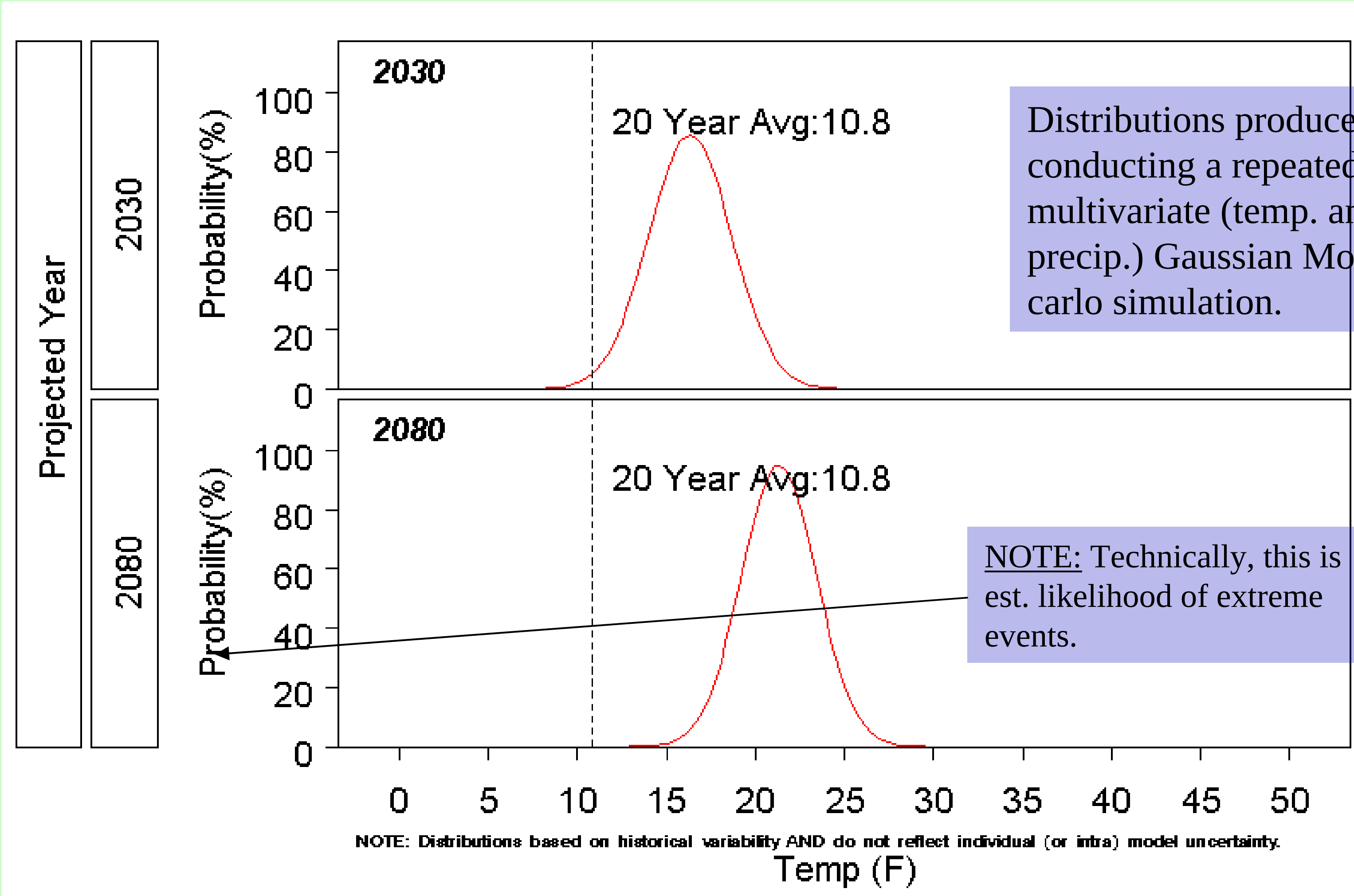

Distributions produced by conducting a repeated multivariate (temp. and precip.) Gaussian Monte-carlo simulation.

NOTE: Technically, this is est. likelihood of extreme events.

Source: ISER (2006)

Climate Projections with Probabilities*

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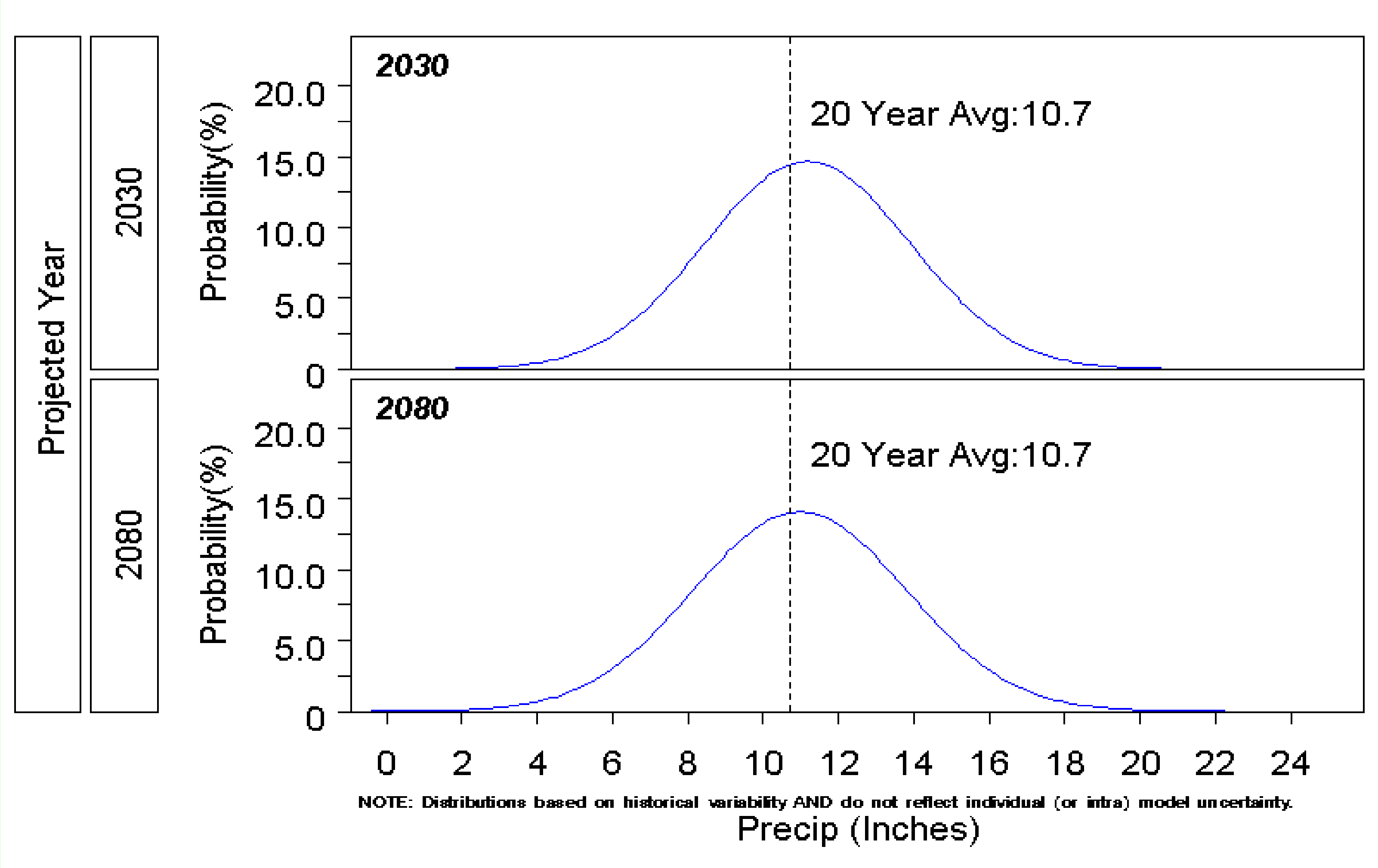
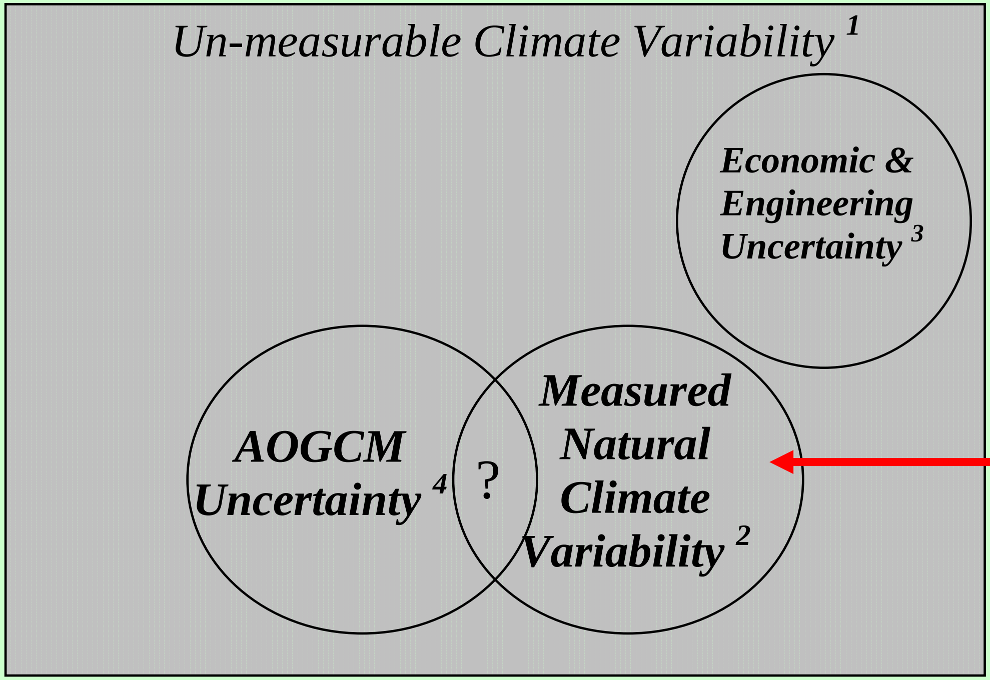


Source: ISER (2006)

Some Thoughts on Conveying Uncertainty in Projections…

Euler Diagram of

Theoretical Climate-Economic-Engineering Uncertainties



To date, this model <u>only</u> takes into account measured variability.

[1]Beyond recorded history ("long memory")
[2]In Alaska, measured climatological recordings date back approximately 50-75 years.
[3]Includes uncertainties relating to future discount rates, replacement/maintenance costs, population growth, structure depreciation rates, etc.
[4]Uncertainties include Atmosphere-Ocean General Circulation Model (AOGCM) statistical biases and measurement errors.

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Import Depreciation Matrix from Engineers

Depreciation Matrix

Reduction in Useful Life (%) per Degree Increase in Annual Temperature

Subclass	Topography	Permafrost Free	Isolated Permafrost	Discontinuous Permafrost	Continuous Permafrost
Courts, Defense, Emergency Services, Energy, Hospitals, Law Enforcement, Misc. Buildings, Schools	Coastal (Exposed)	-5.0%	-5.1%	-5.2%	-5.5%
	Coastal (Protected)	-1.0%	-1.1%	-1.2%	-1.5%
	Interior	0.0%	-0.1%	-0.2%	-0.5%
Airports, Bridges, Grid, Harbors, Railroads, Roads, Sewers, Telecommunications, Telephone, Water	Coastal (Exposed)	-7.5%	-7.6%	-7.7%	-8.0%
	Coastal (Protected)	-1.0%	-1.1%	-1.2%	-1.5%
	Interior	0.0%	-0.1%	-0.2%	-0.5%

Reduction in Useful Life (%) per Inch Increase in Annual Precipitation

Subclass	Topography	Permafrost Free	Isolated Permafrost	Discontinuous Permafrost	Continuous Permafrost
Courts, Defense, Emergency Services, Energy, Hospitals, Law Enforcement, Misc. Buildings, Schools	Coastal (Exposed)	-5.0% to 0%	-5.0% to 0%	-5.0% to 0%	-5.0% to 0%
	Coastal (Protected)	-5.0% to 0%	-5.0% to 0%	-5.0% to 0%	-5.0% to 0%
	Interior	-5.0% to 0%	-5.0% to 0%	-5.0% to 0%	-5.0% to 0%
Airports, Bridges, Grid, Harbors, Railroads, Roads, Sewers, Telecommunications, Telephone, Water	Coastal (Exposed)	-7.5% to 0%	-7.5% to 0%	-7.5% to 0%	-7.5% to 0%
	Coastal (Protected)	-7.5% to 0%	-7.5% to 0%	-7.5% to 0%	-7.5% to 0%
	Interior	-7.5% to 0%	-7.5% to 0%	-7.5% to 0%	-7.5% to 0%

Notes on Estimating Depreciation Rates from Climate Change

- Depreciation rates (i.e. adjustments to useful life of infrastructure from temperature and precip. changes) were estimated by Professor Orson Smith, UAA Chair of Civil Engineering.

- Depreciation rates were roughly estimated by infrastructure type, state of permafrost layer (e.g. continuous), general topography (e.g. protected coast), and proximity to coastal or interior floodplain.

- Future funding is needed for engineers to study different functional forms for rates of depreciation, underlying soil characteristics, updated permafrost coverage information, etc.

Conducting Lifecycle Analysis

Infrastructure Type		Replacement Cost	Units	Baseline Useful Life (years)
Agriculture		N/A	N/A	N/A
Airport	$	5,664,812	Whole	10
Bridges	$	10,000	Per foot	40
Courts	$	16,150,618	Whole	40
Defense	$	305,441	Whole	40
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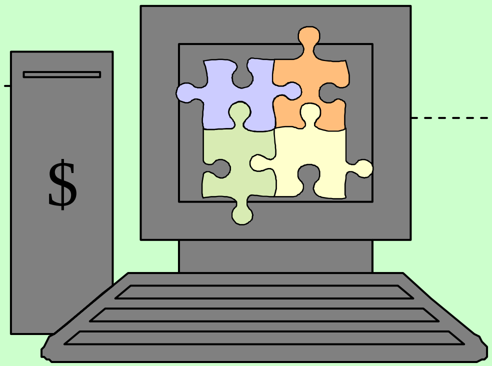

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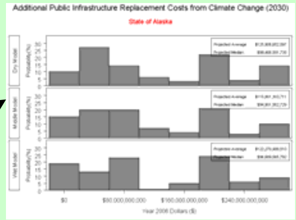

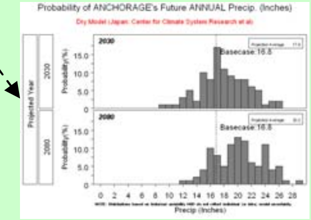

Graphs

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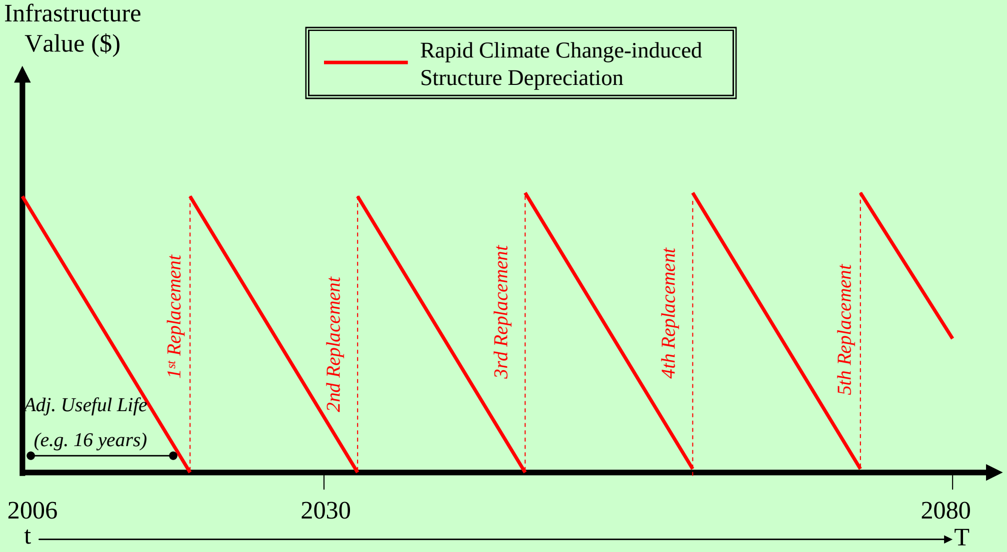
Calculating the Exposure of Alaska Infrastructure to Climate Change

I. ACCELERATED CASE: Depreciate infrastructure using techniques that proxy shortened (lengthened) asset lifespan due to coastal erosion, melting permafrost, flooding, sea-level rise, etc.

II. Calculate present value of altered replacement scenario. (PV_{ACC})

III. Addl Replacement Costs = (PV_{ACC}) - (PV_{BASE})



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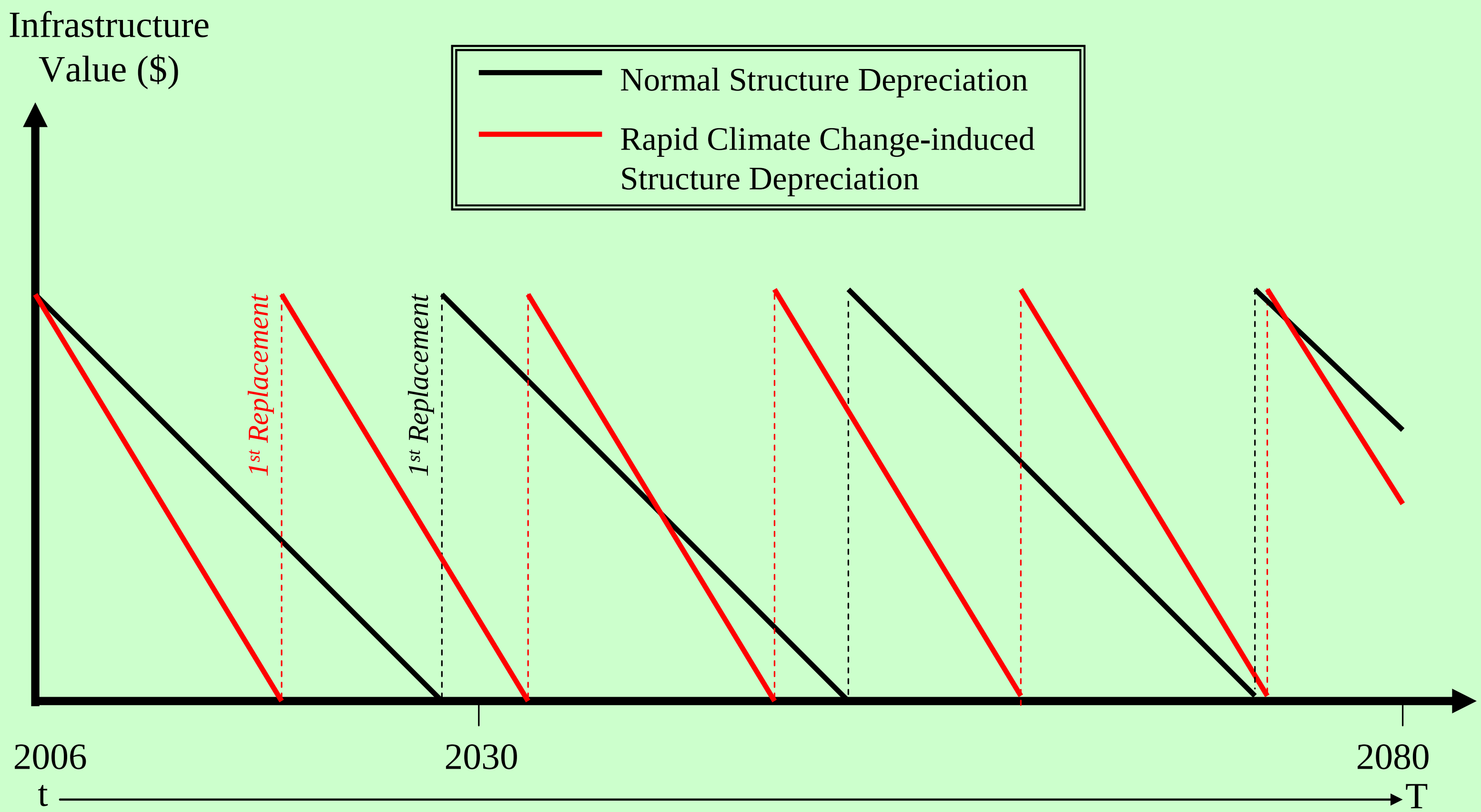
Calculating the Exposure of Alaska Infrastructure to Climate Change



Model Functional Form

r = Real Discount Rate (i.e. 2.85%)
i = Year
j = Infrastructure Type

Base Case

$$\theta_j = \frac{\text{Replacement Value}_j}{\text{Basecase Useful Life}_j}$$

$$PV_{\text{Base}} = \sum_{j=1}^{20} \sum_{i=2006}^{2030} \frac{\theta_j}{(1+r)^{i-2006}}$$

Climate Change

$$\Delta_j = \frac{\text{Replacement Value}_j}{\text{Adjusted Useful Life}_j}$$

$$PV_{\text{Climate Change}} = \sum_{j=1}^{20} \sum_{i=2006}^{2030} \frac{\Delta_j}{(1+r)^{i-2006}}$$

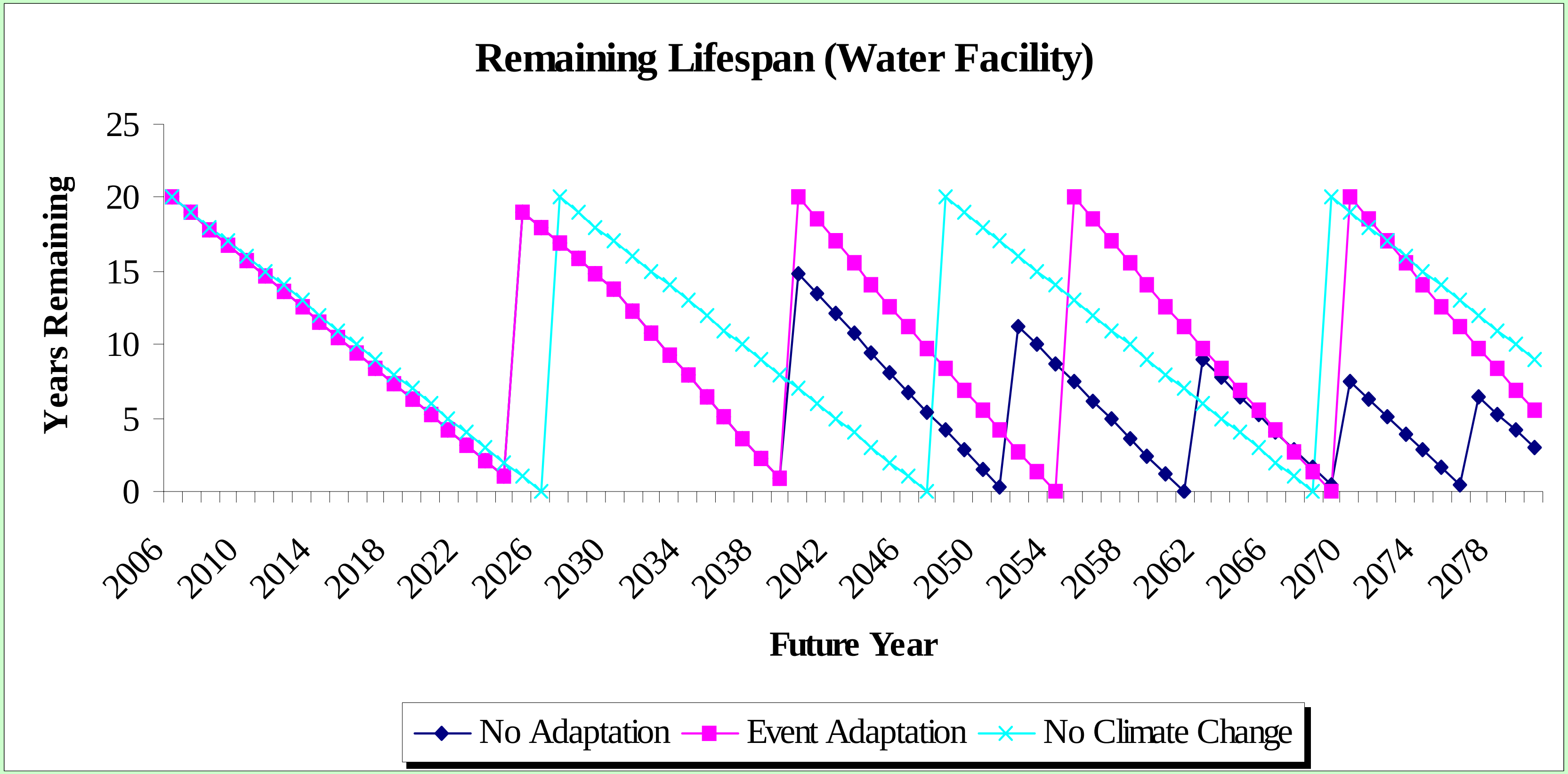
$$\boxed{\Phi_{2030} = PV_{\text{Climate Change}} - PV_{\text{Base}}}$$

Φ_{2030} = Additional Public Infrastructure Replacement Costs from Climate Change

Structural Adaptation Component

* 20% Damage Threshold Triggers Adaptation *

* 5% Cost Increase to Adapt Structure *



Source: ISER/CU (2007)

Cost of Public Infrastructure Vulnerable to Climate Change

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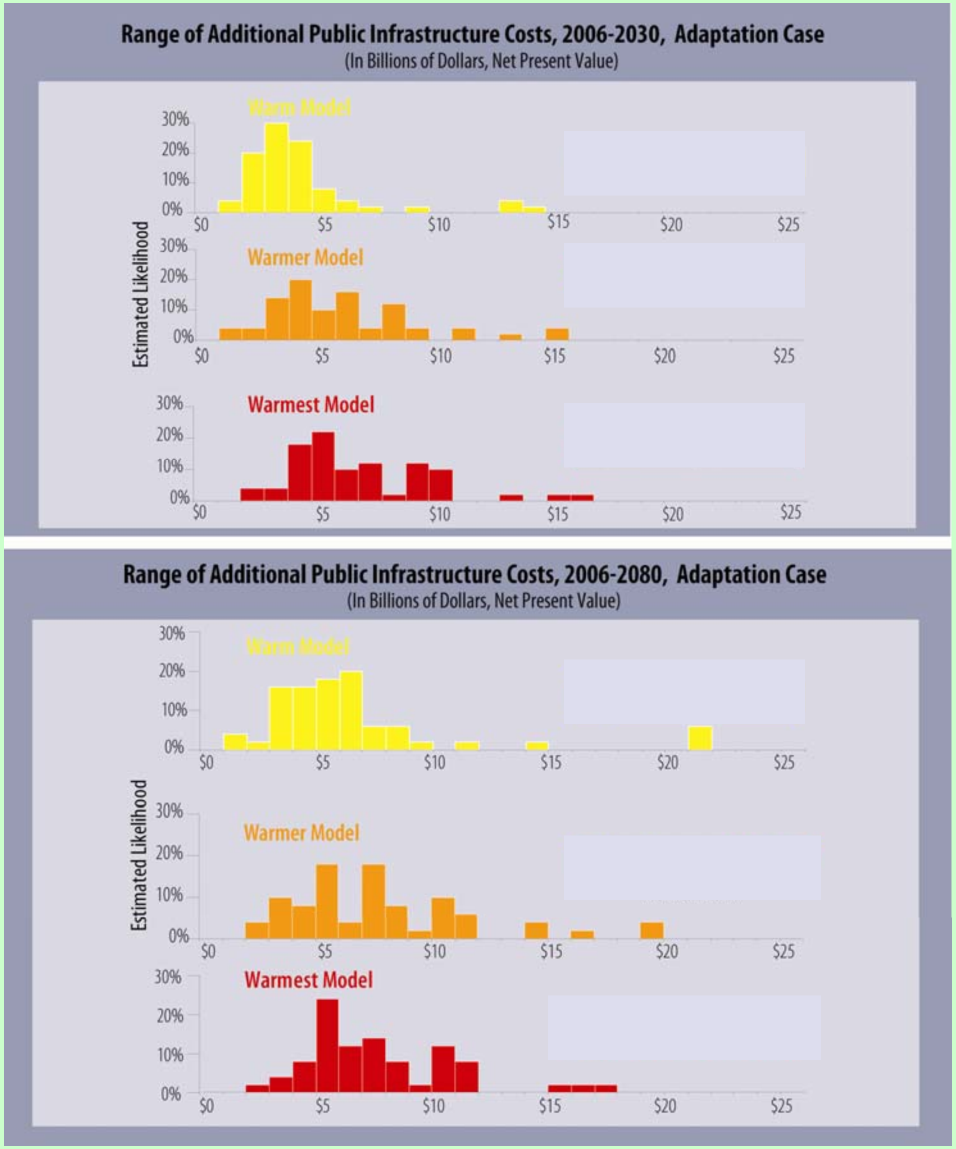
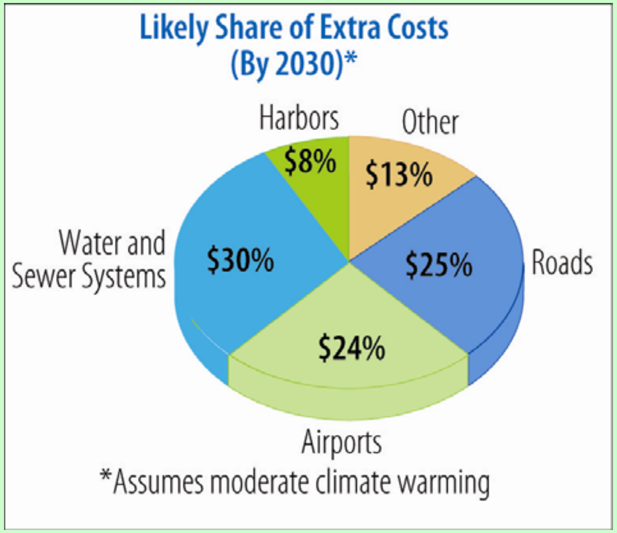
Estimated Likelihoods





Preliminary **and Assumes Plausible Adaptations**

Source: ISER (2007)

ISER/Engineering Wish List

- Disaggregate replacement costs.
- Add maintenance costs.
- Get more up-to-date information for APID
- Develop more sophisticated depreciation algorithms given topography and infrastructure type.
- Incorporate actual AOGCM model uncertainty.
- Include local sea-level (inundation and subsidence) estimates into model along with better permafrost information.
- Run scenarios at ARSC in Fairbanks.
- Deal with population growth.
- Collaborate with other state, federal, university researchers.

Conclusion

- Regardless of cause, effects of climate change are being observed in many parts of Alaska.

- Future projections show a consensus of significant changes in the foreseeable future, particularly for the Northern part of the state.

- Damages to infrastructure could be large (i.e. *several billions of today's dollars*), but there is little reliable information "on the ground" detailing the degree and location of impacts.

- NCEP/ACF/RurALCAP sponsored research will allow ISER/UAA School of Engineering to continue to build a model to roughly estimate these impacts and facilitate the adaptation/mitigation debate.

Final Thoughts from the USARC….

" Expected values of relocation and rehabilitation can be developed, given estimates of per-mile design and construction costs. A *master plan* of climate-change-induced major relocation and rehabilitation projects can be formed with this information."

-U.S. Arctic Research Commission, 2003

Acknowledgements

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- NCAR (Boulder, CO): Dr. Claudia Tebaldi and Seth McGuinness
- Stratus Consulting (Boulder, CO): Joel Smith and Carolyn Wagner
- SAS Listserv (University of Georgia): Too many to name.
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