FEBRUARY 3, 2014

GEORGE ANNANDALE

SUSTAINABLE WATER SUPPLY AND CLIMATE CHANGE

n to US Bureau of Reclamation

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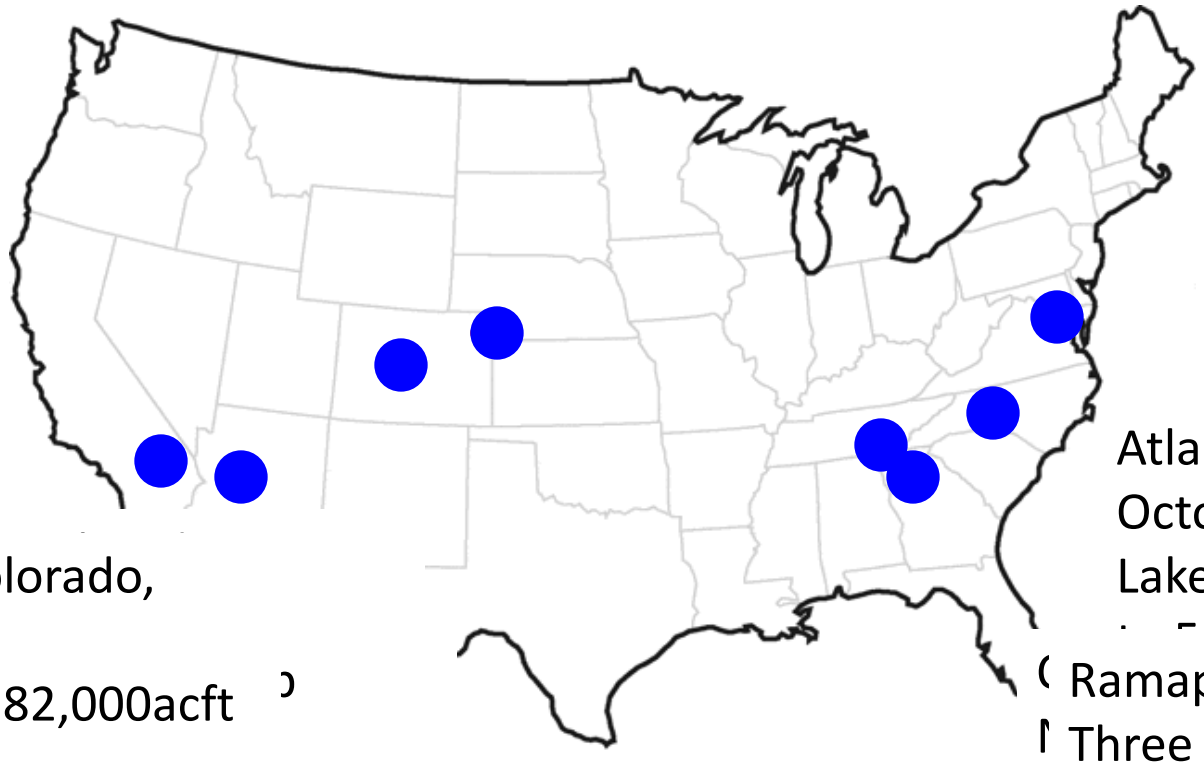
WATER SUPPLY IN THE US

US GAO – 36 States expect water shortages under normal conditions



Republic River: Colorado, Nebraska, Kansas
2005 – NE pumps 82,000acft too much
Kansas to Supreme Court
Shut off all pumps w.in 2.5 mi
Fallow 500,000 acres in NE

Atlanta GA
October 2007
Lake Lanier – supply

Ramapo, New York
Three Drought Declarations: 1995 – 2002
Three-Quarters of Supply: Groundwater (depletion)

WHAT IS SUSTAINABLE DEVELOPMENT?

"Sustainable development seeks to meet the **needs and aspirations** of the **present** without compromising the ability to meet those of the **future**"

- Brundtland Commission Report: "***Our Common Future (1987)***"

INTERGENERATIONAL EQUITY

INTERGENERATIONAL EQUITY

- Current needs and aspirations to be met – NOT COMPROMISED
- Development to proceed in a way that will NOT COMPROMISE the ability to satisfy FUTURE needs and aspirations
- Environmental Stabilization – A DESIRABLE CONSEQUENCE of Sustainability Development

SUSTAINABLE DEVELOPMENT

HOW TO SUSTAINABLY DEVELOP A RESOURCE

- RENEWABLE resources are used at a RATE that is smaller than its RATE of regeneration

- EXHAUSTIBLE resources are used at a RATE that is smaller than the RATE of development of renewable substitutes, and

- POLLUTION does not exceed the RATE by which the environment can assimilate it.

  - Herman Daly

RENEWABLE AND EXHAUSTIBLE RESOURCES

WATER:
RENEWABLE OR EXHAUSTIBLE?

7,972mi

EXHAUSTIBLE

RENEWABLE

All Water on Earth

864mi

Accessible Fresh Groundwater

42mi

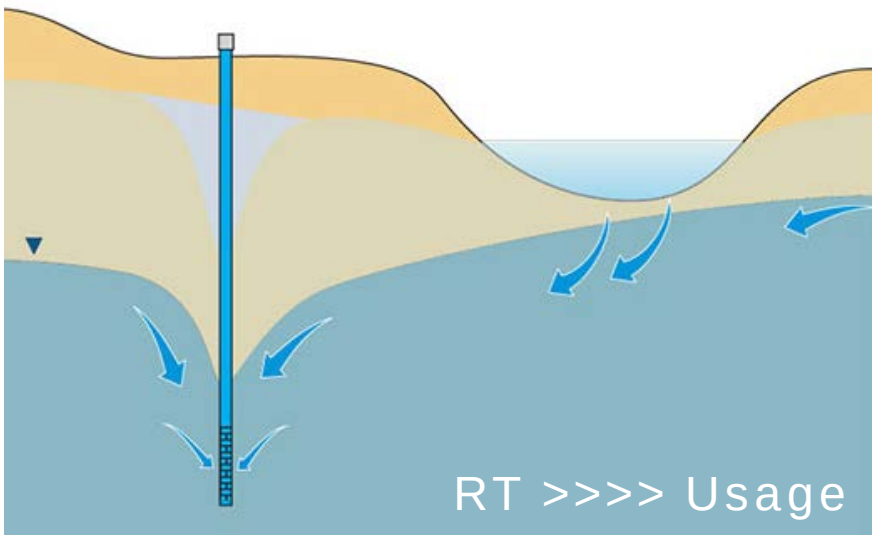
All Rivers

10mi

GROUNDWATER OR RIVER WATER?

POTENTIAL FOR SUSTAINABLE DEVELOPMENT

Daily Use of Water

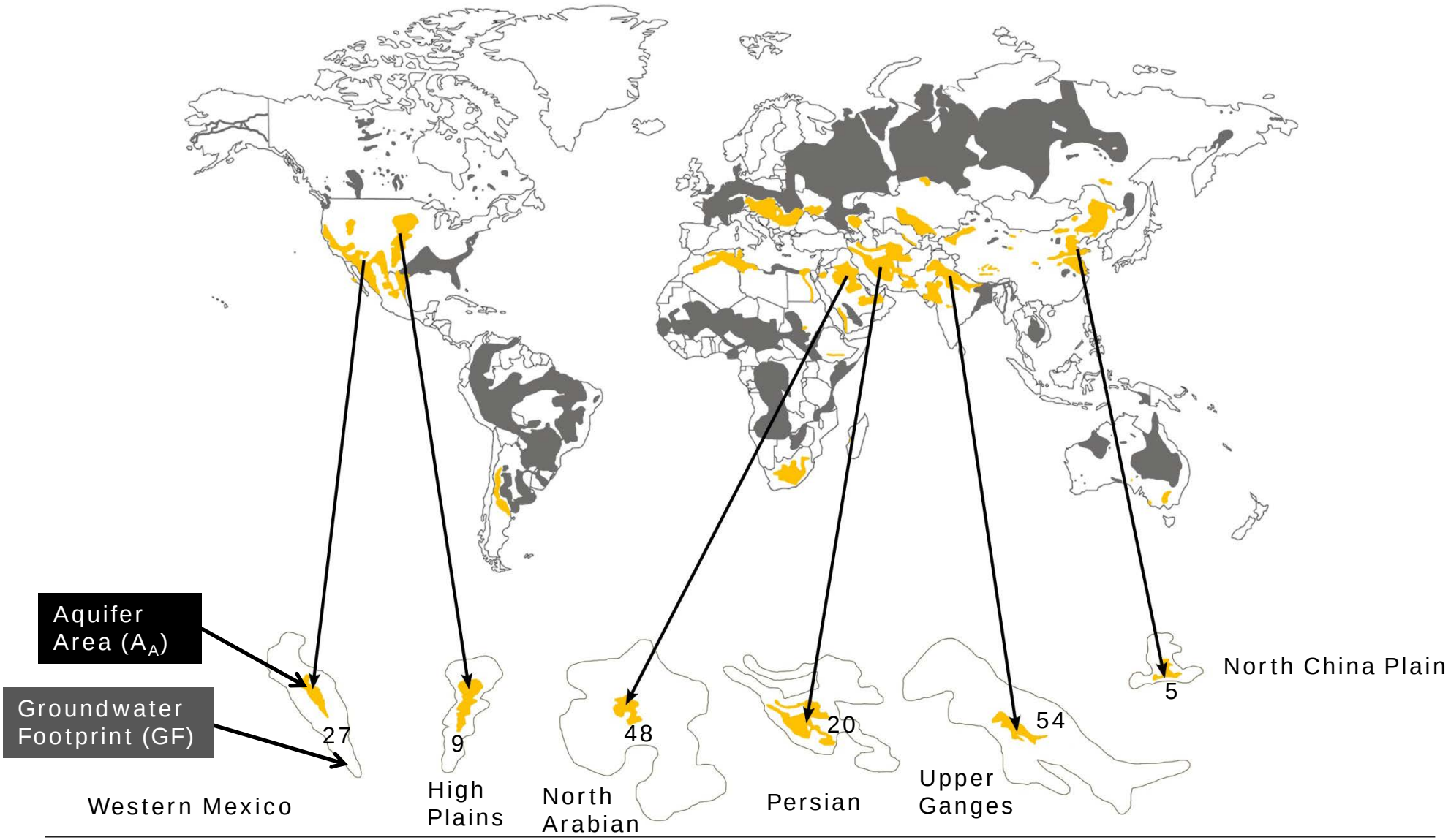


Residence Time = 1,400 years

Residence Time = 16 to 18 days

GROUNDWATER FOOTPRINT

GLOBAL FOOTPRINT = 3.5



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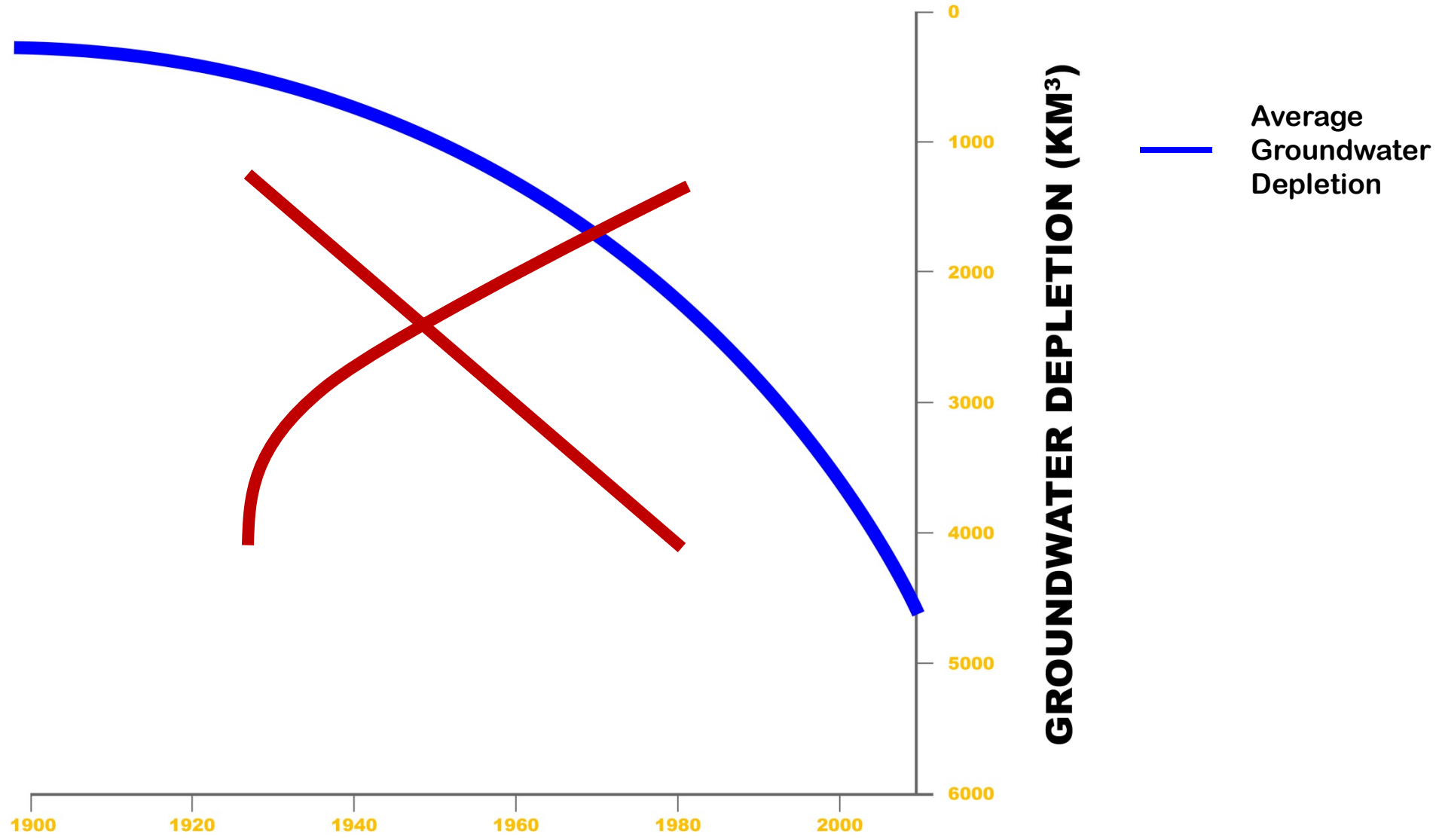
GLOBAL GROUNDWATER DEPLETION

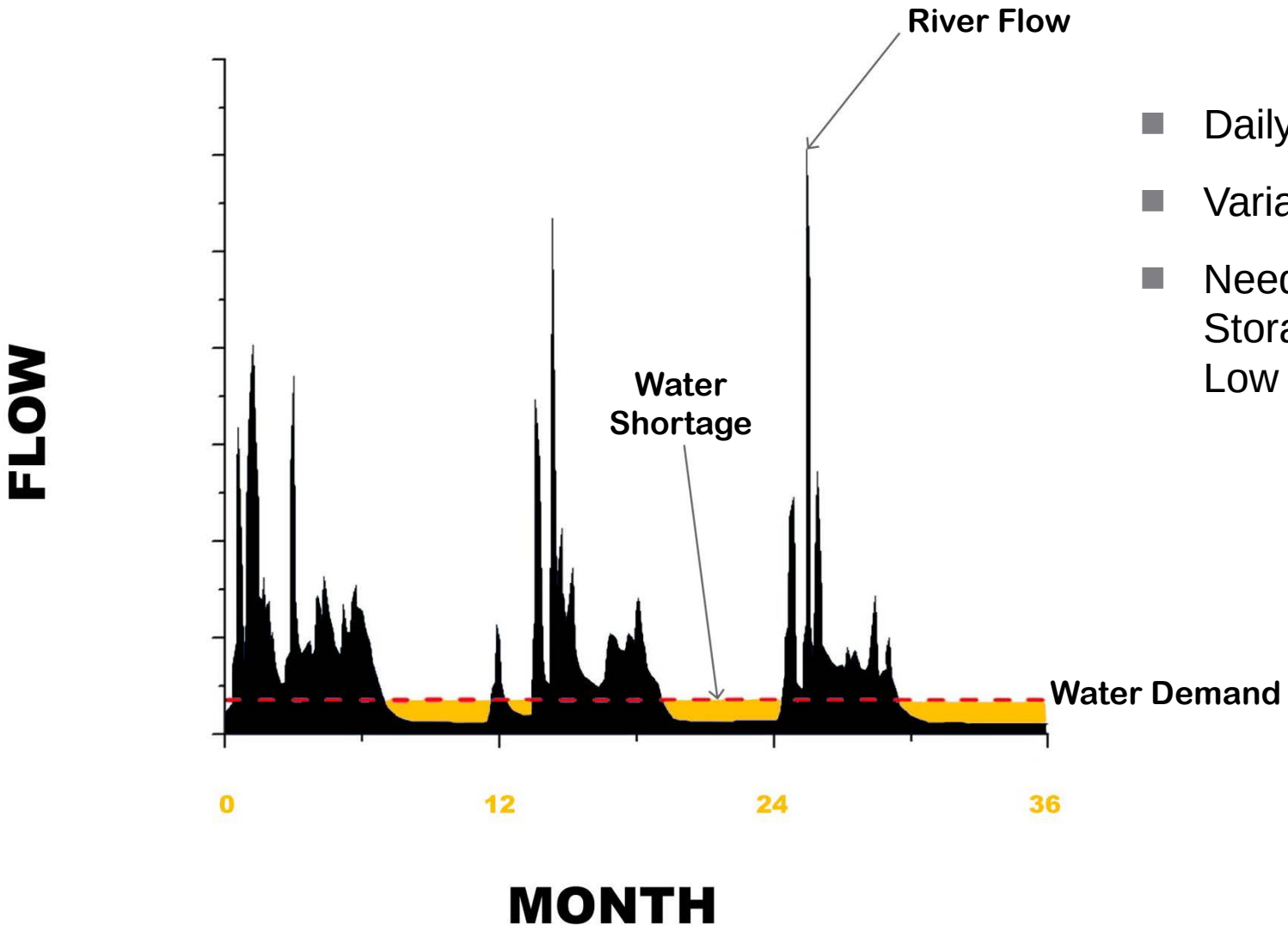


RIVER WATER

PREFERRED SOURCE OF FRESH WATER

LOW HYDROLOGIC VARIABILITY

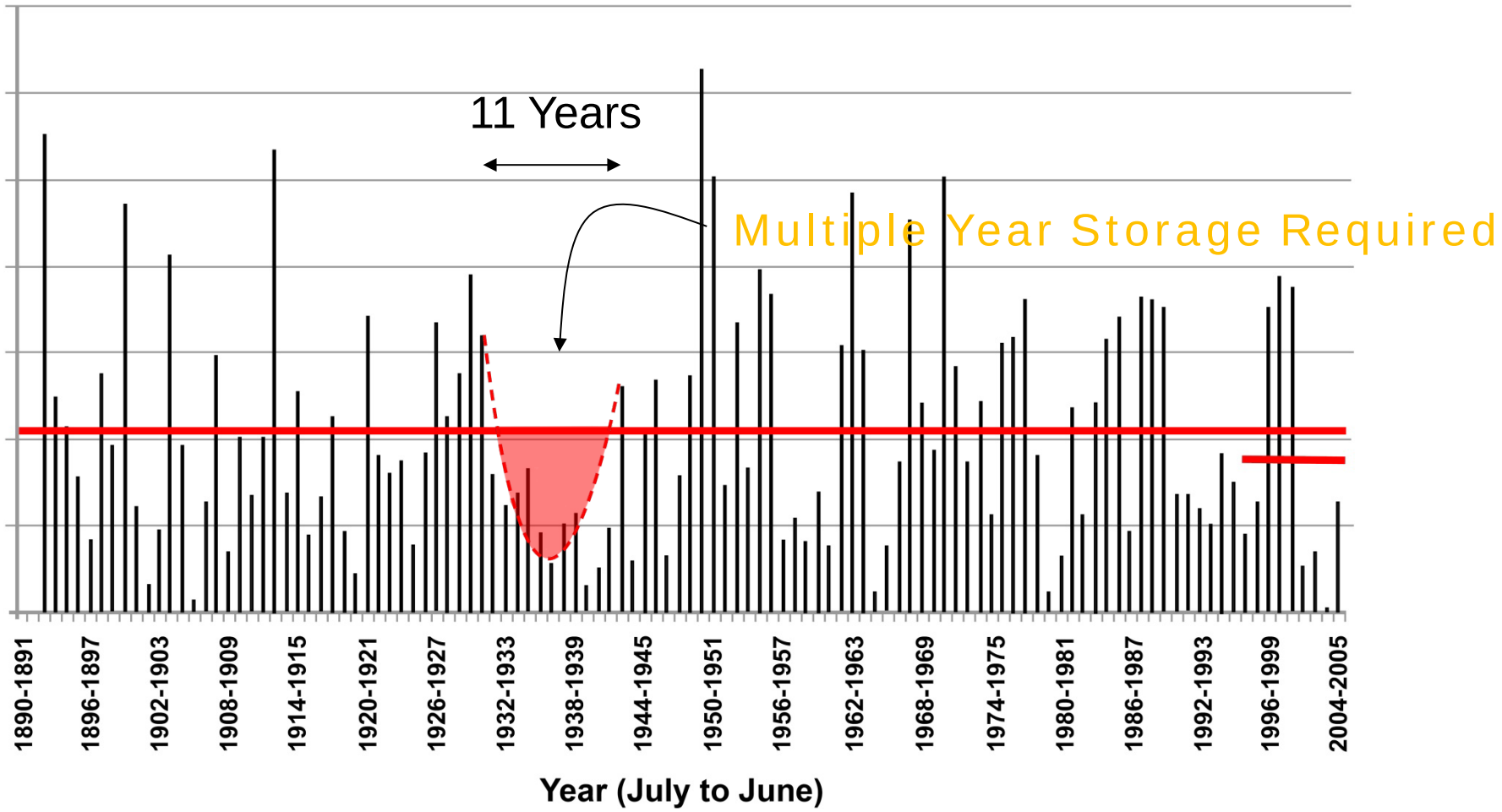
SEASONAL LOW FLOWS ONLY



- Daily Renewal
- Variable Flow
- Need for Run-of-River Storage to Supply during Low Flow Season

HIGH HYDROLOGIC VARIABILITY

MULTIPLE YEAR DROUGHTS



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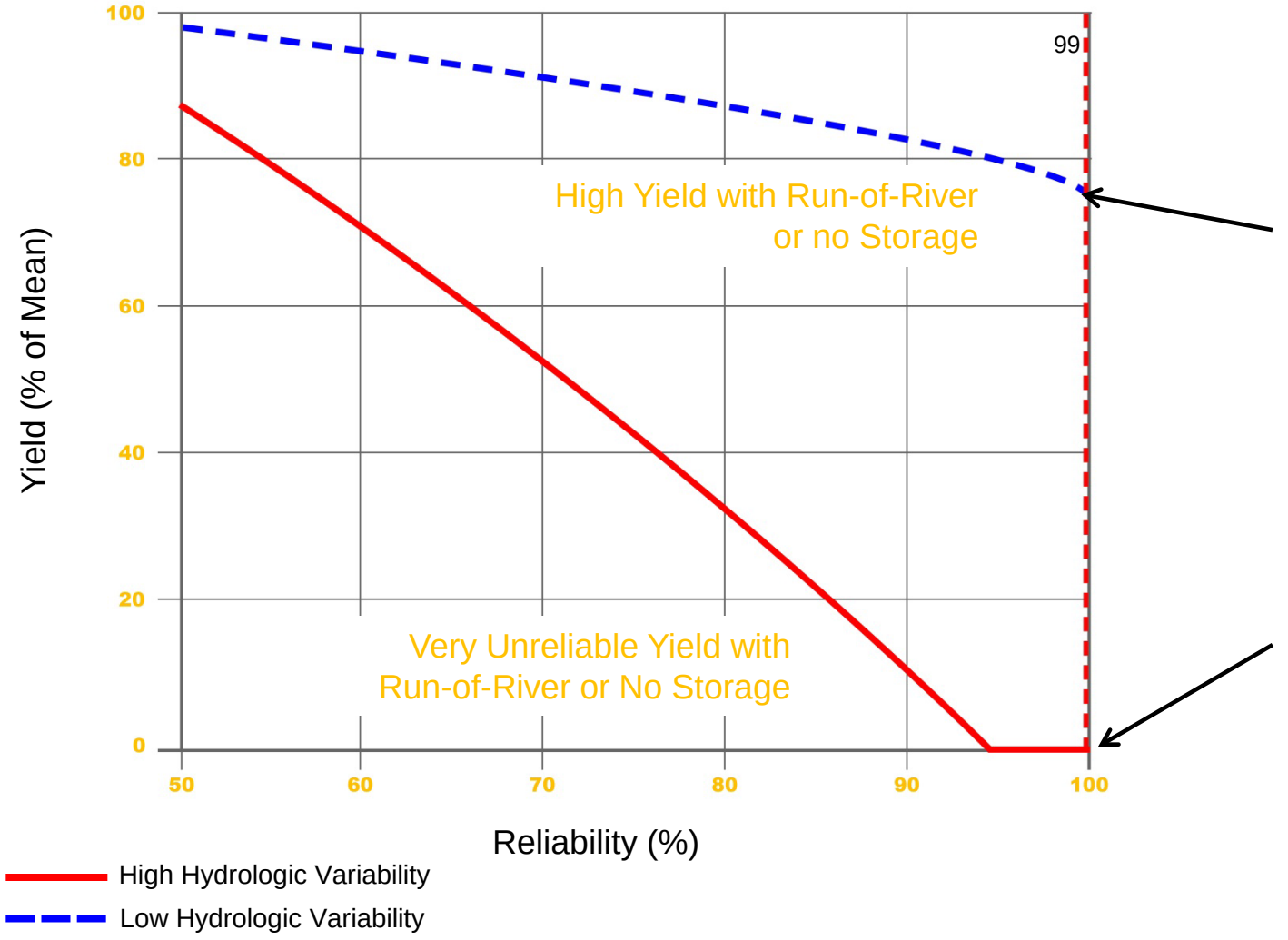
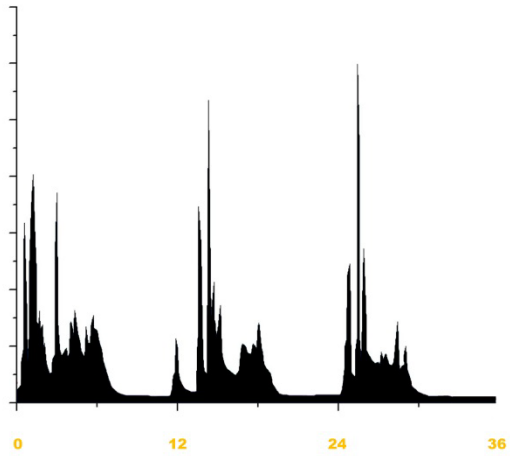
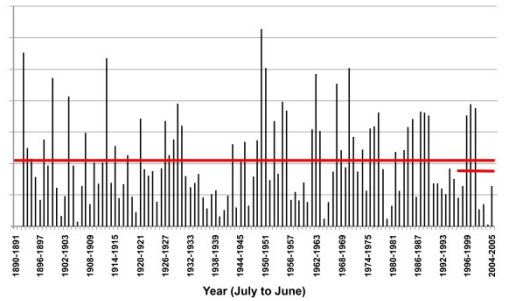
HYDROLOGIC VARIABILITY DETERMINES DAM CHOICE





LOW VARIABILITY



HIGH VARIABILITY

$$\alpha' = 1 + c_v \cdot z_\gamma$$

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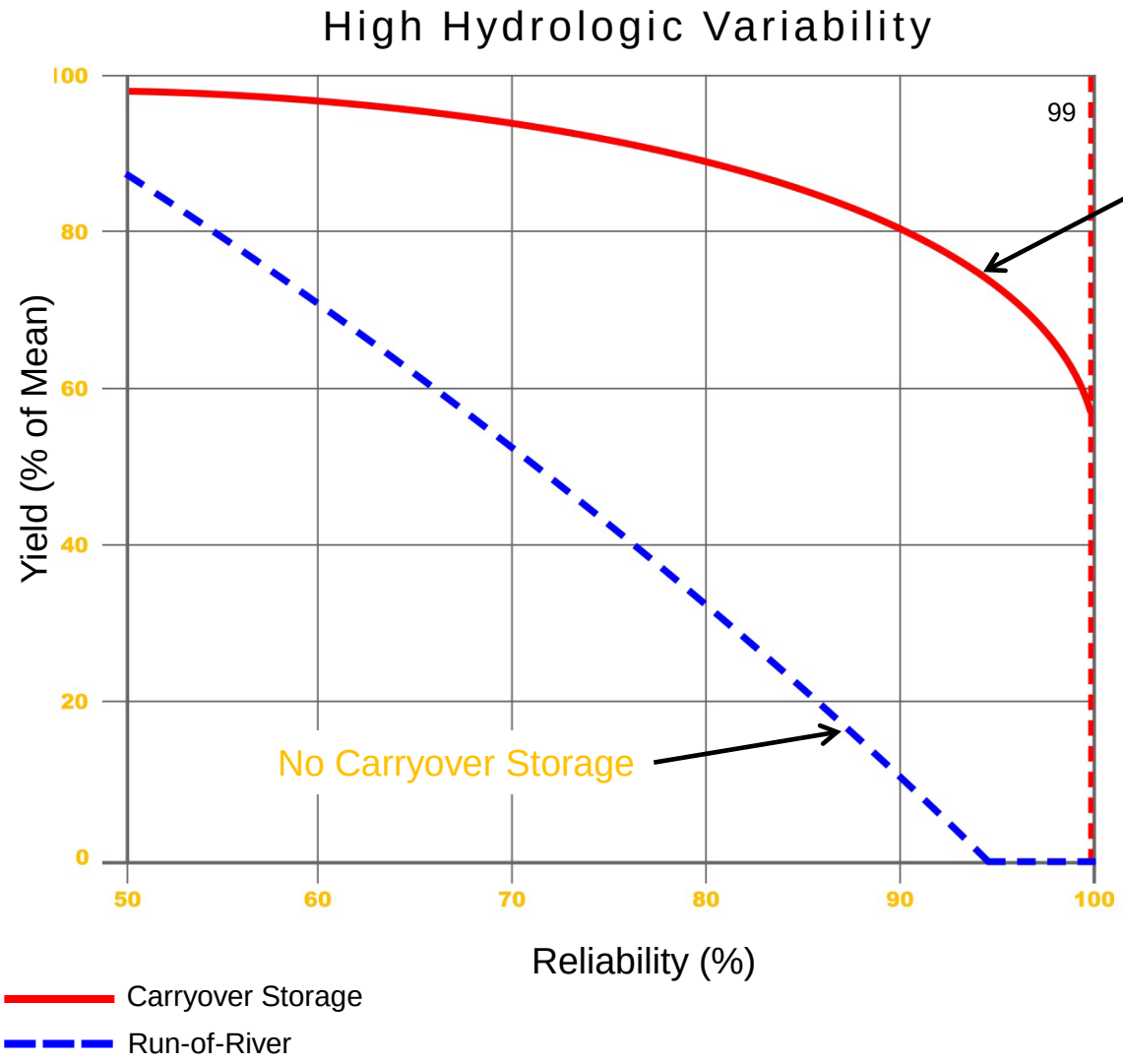
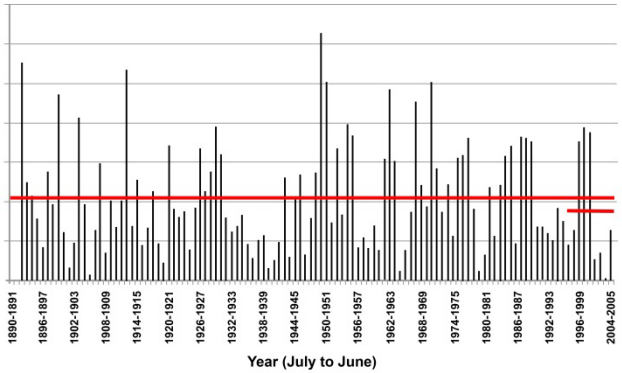
VALUE OF CARRY-OVER STORAGE IN REGIONS WITH HIGH HYDROLOGIC VARIABILITY



WITH DAM AND CARRYOVER STORAGE = 1X MAF



$$\alpha = 1 - \frac{z_\gamma^2 \cdot c_v^2}{4 \cdot \tau}$$

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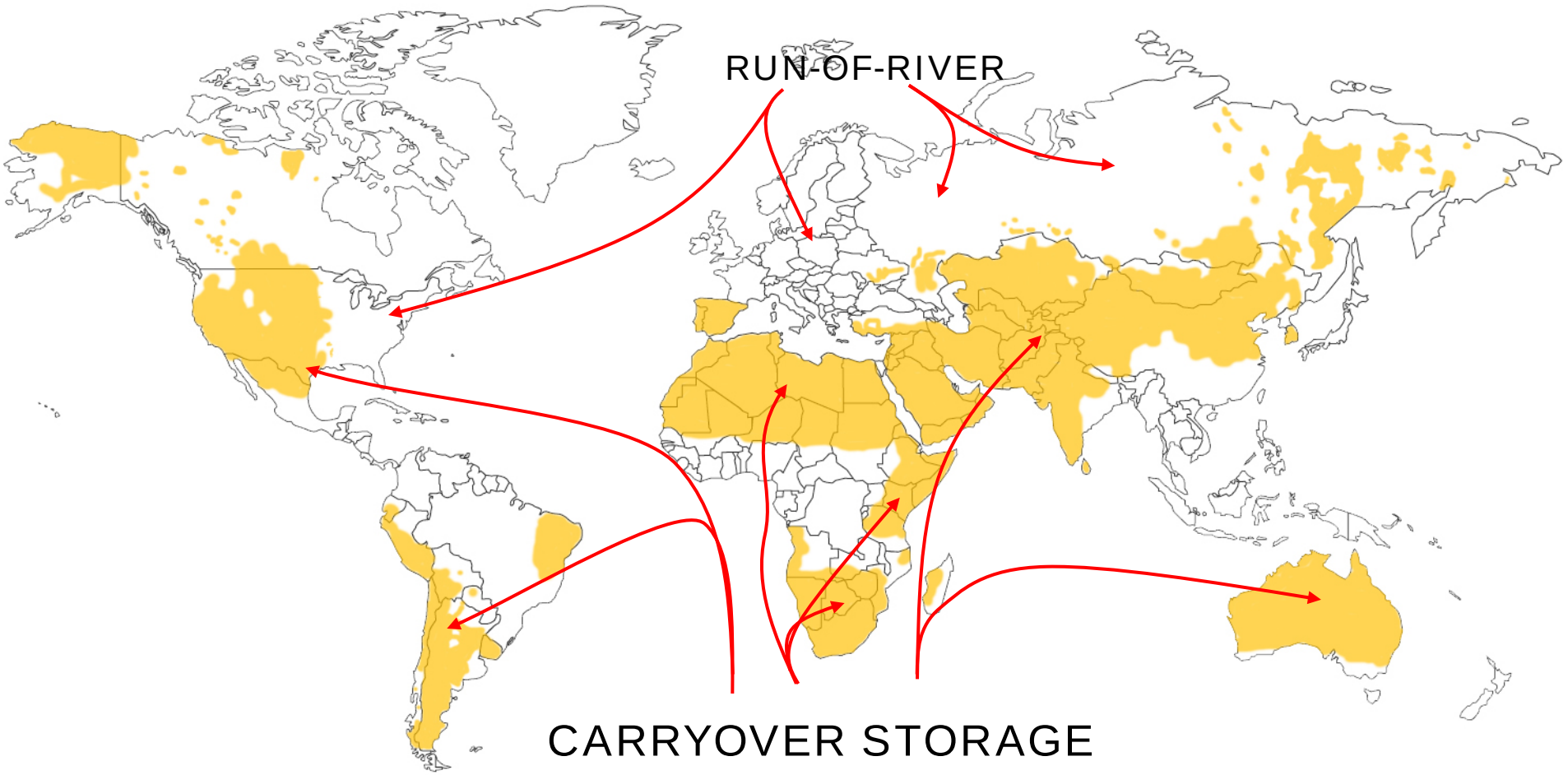
RUN-OF-RIVER AND CARRYOVER STORAGE REGIONS



$$n_{crit} = \frac{z_\gamma^2 \cdot c_v^2}{4 \cdot (1-\alpha)^2}$$

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CLIMATE CHANGE AND WATER SUPPLY

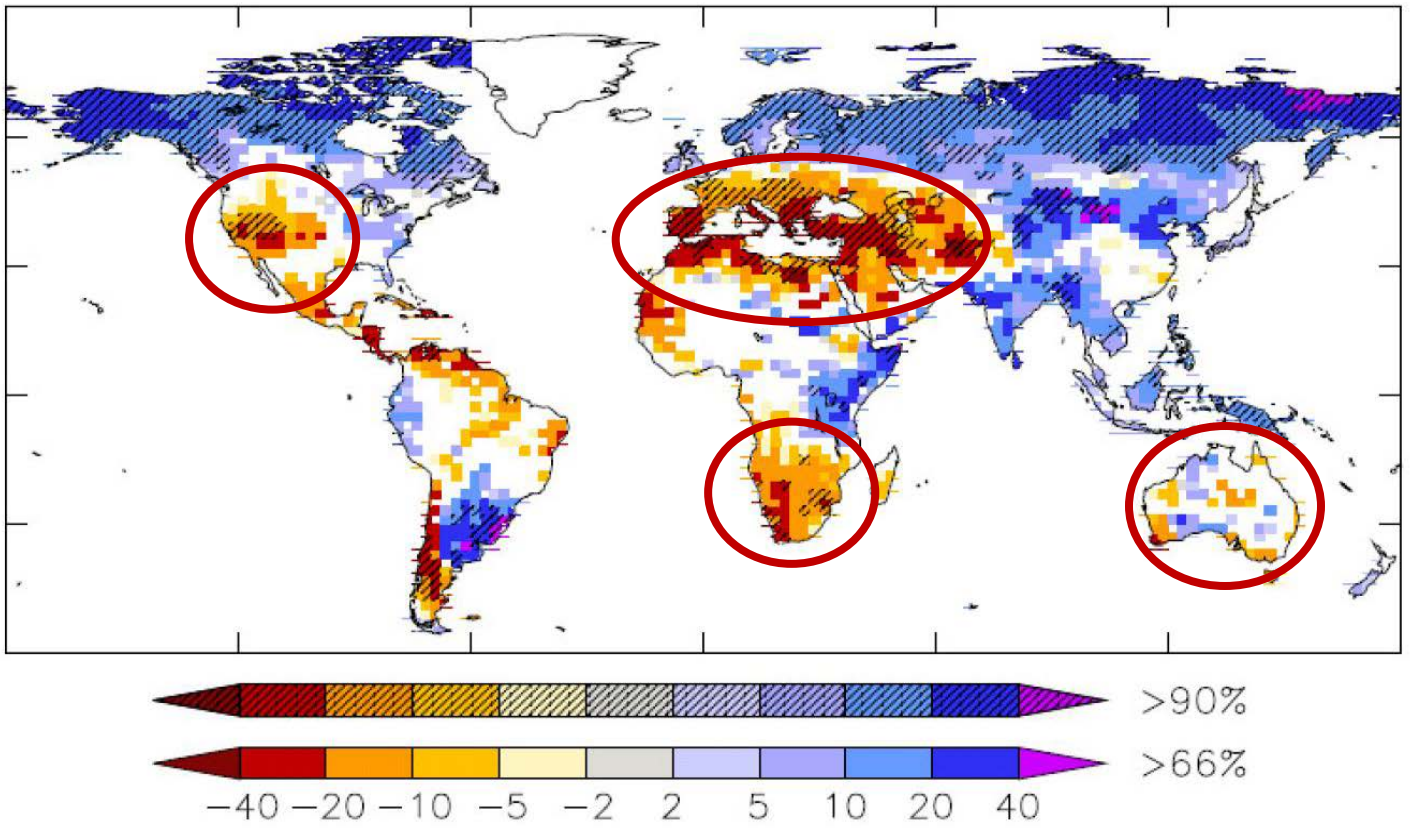
TWO IMPORTANT VARIABLES

CHANGE IN MEAN ANNUAL RIVER FLOW

CHANGE IN HYDROLOGIC VARIABILITY

CLIMATE CHANGE

MEAN ANNUAL FLOW INCREASE/DECREASE



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CLIMATE CHANGE

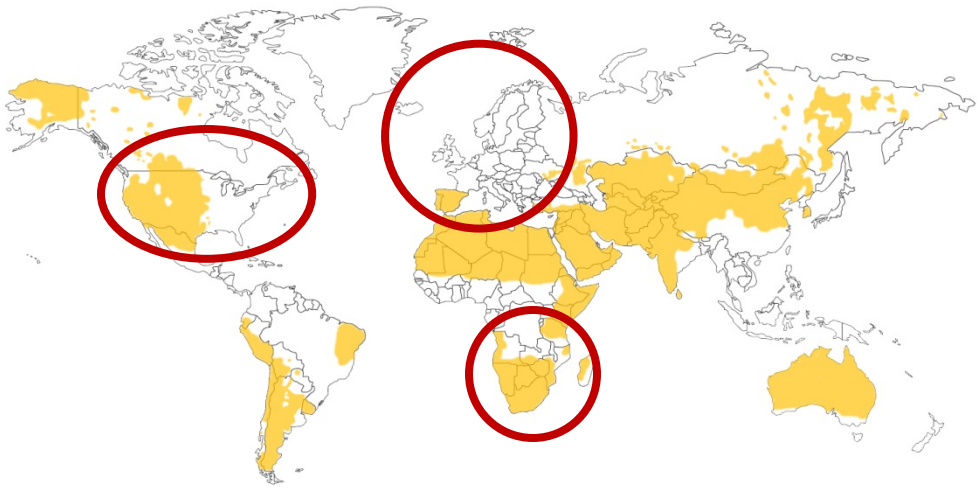
HYDROLOGIC VARIABILITY TO INCREASE

Inadequate Knowledge

CLIMATE CHANGE

HOW MUCH WOULD VARIABILITY INCREASE

Current Conditions



Assume 25% Increase in Variability

$$n_{crit} = \frac{z_\gamma^2 \cdot c_v^2}{4 \cdot (1-\alpha)^2}$$

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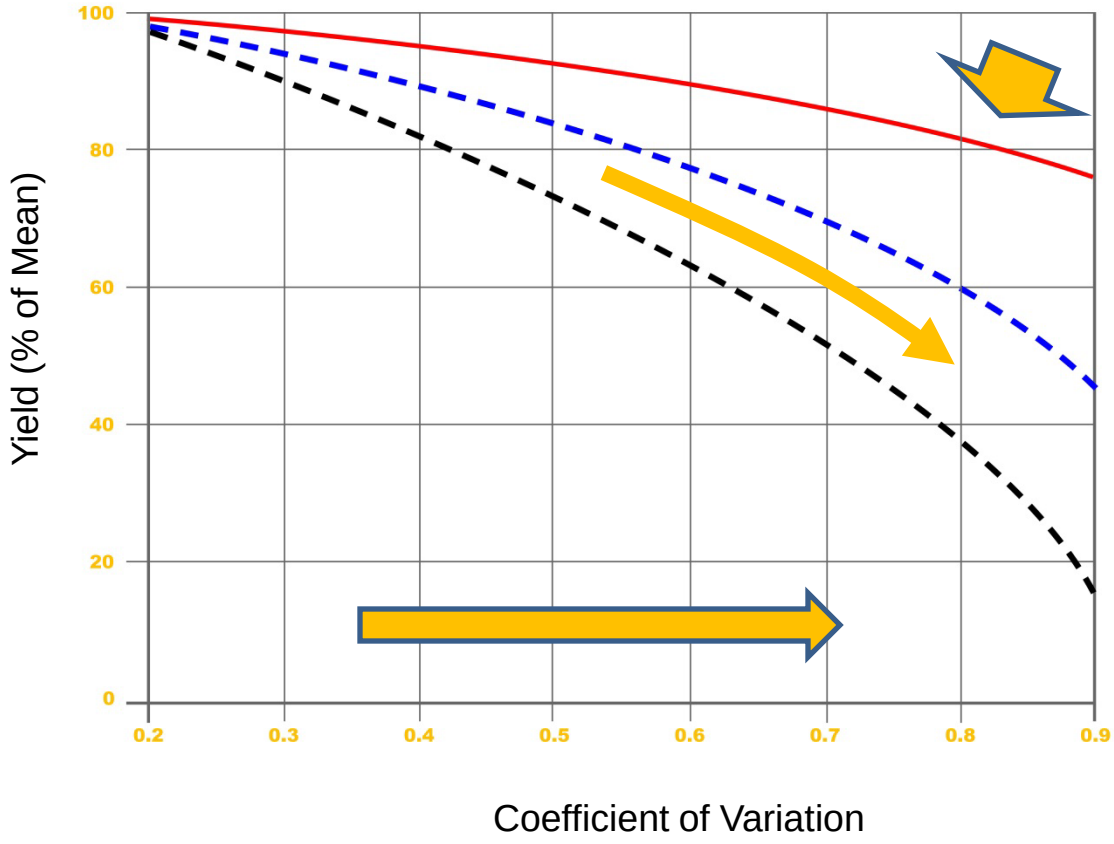
HOW TO PREPARE FOR CLIMATE CHANGE:

DESIGN AND BUILD ROBUST INFRASTRUCTURE

- Increased Hydrologic Variability due to Climate Change
- Reduction in Yield
- To Maintain Reliability of Water Supply
  - Construct Reservoir Storage Spaces that are as LARGE as possible



$$\alpha = 1 - \frac{z_\gamma^2 \cdot c_v^2}{4 \cdot \tau}$$

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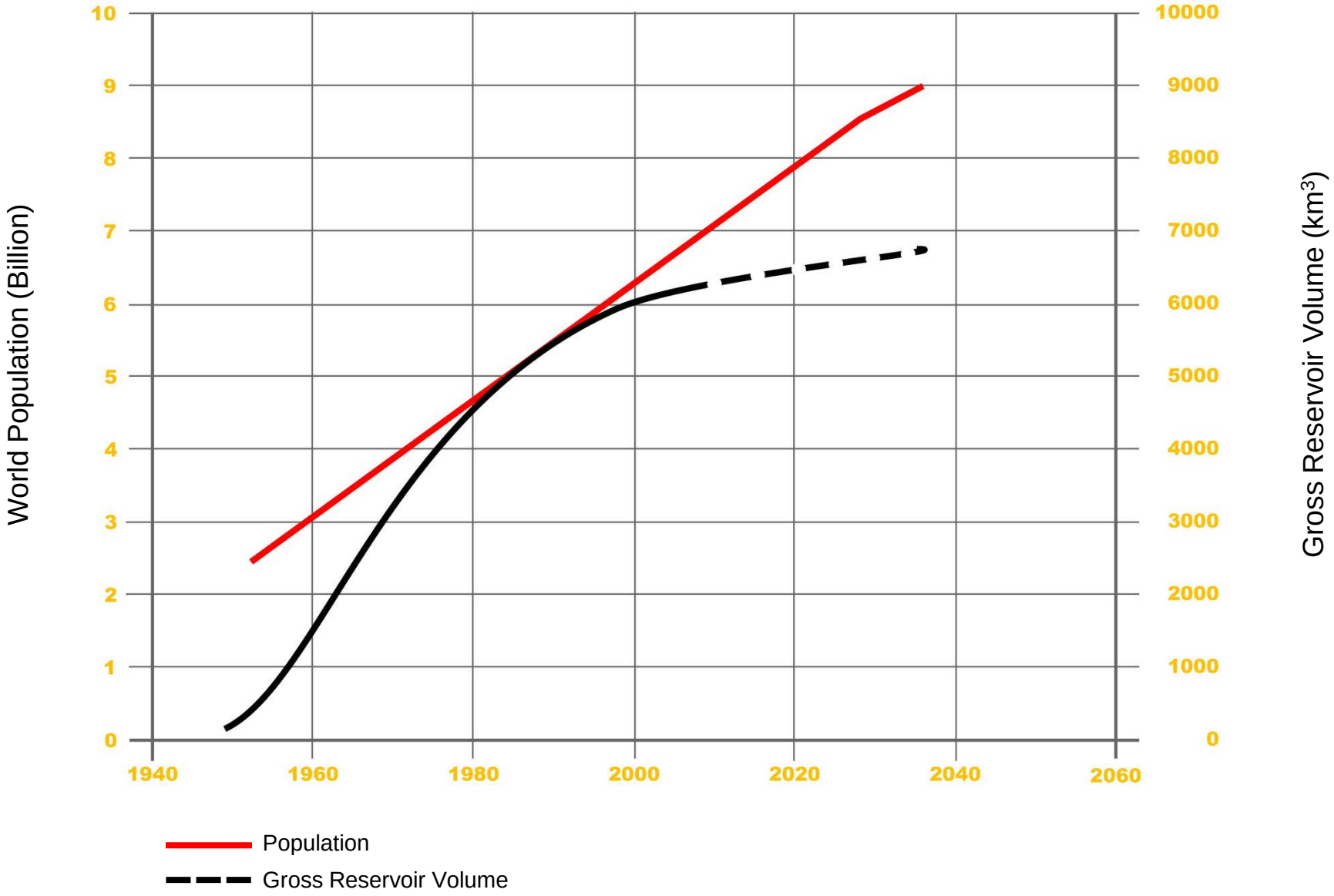
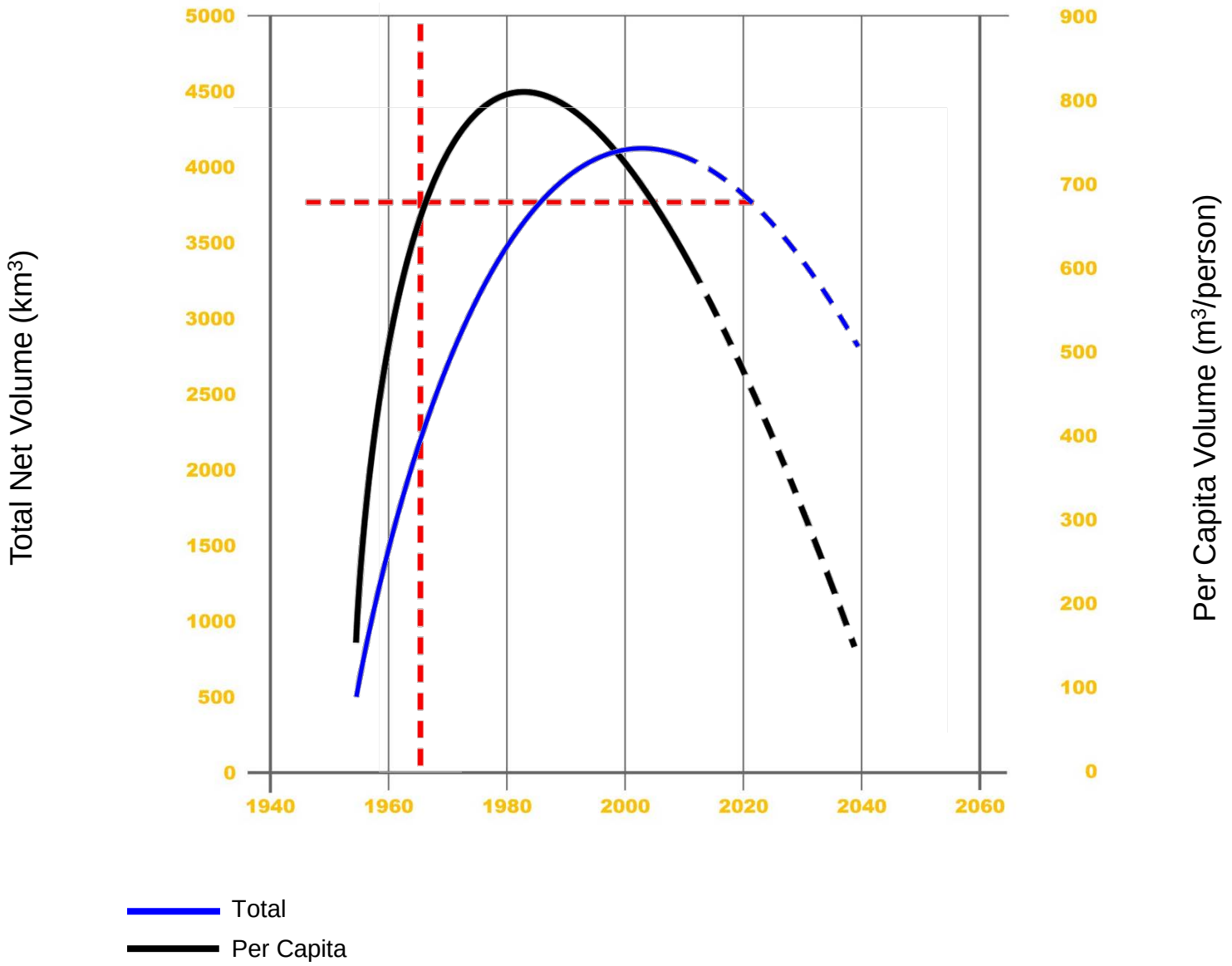
DAM CONSTRUCTION AND GLOBAL POPULATION



RESERVOIR SEDIMENTATION –

THE STORAGE SPACE ENEMY

GLOBAL STORAGE IN LARGE DAMS



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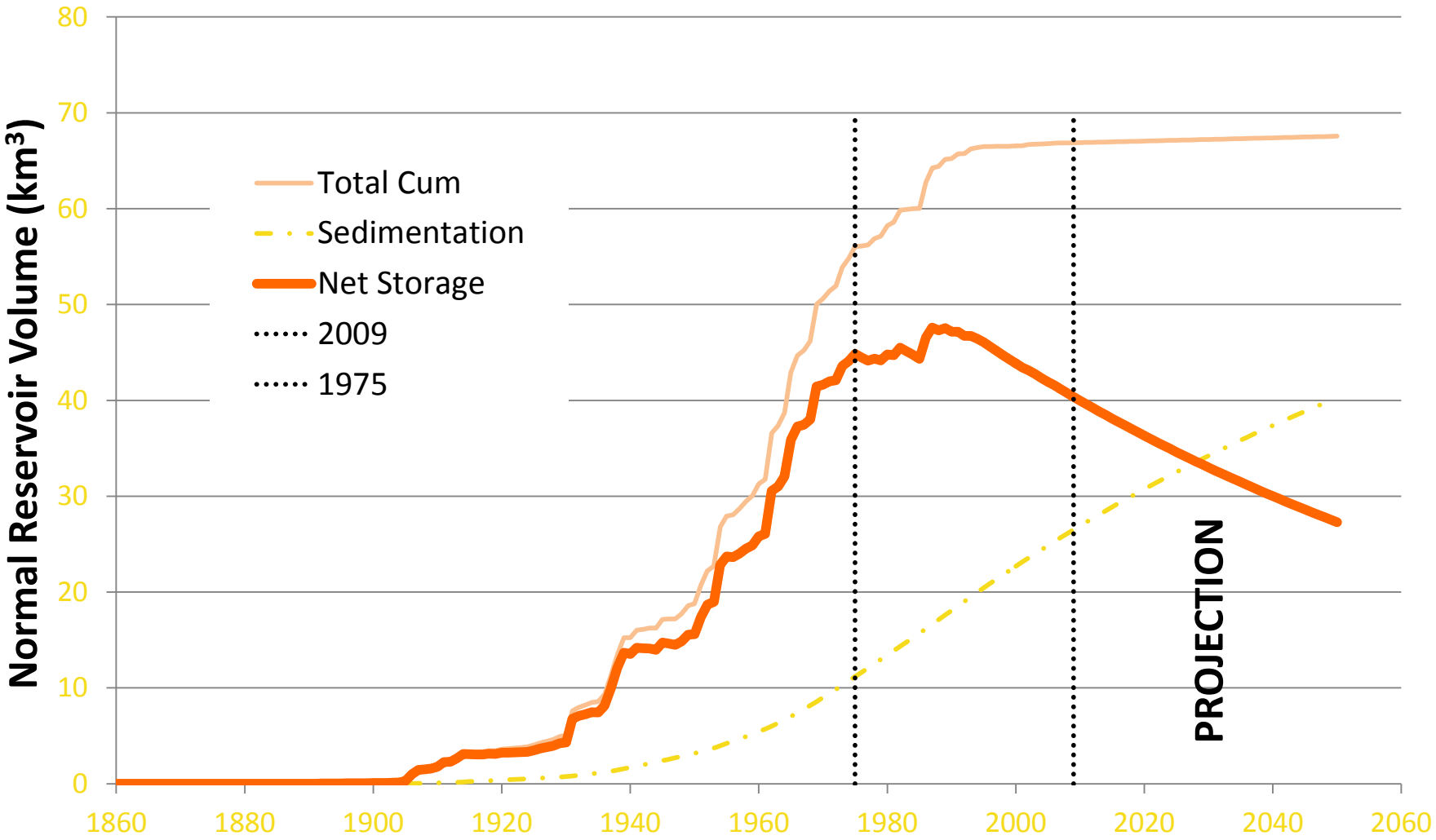
US STORAGE
LARGE WATER SUPPLY & IRRIGATION



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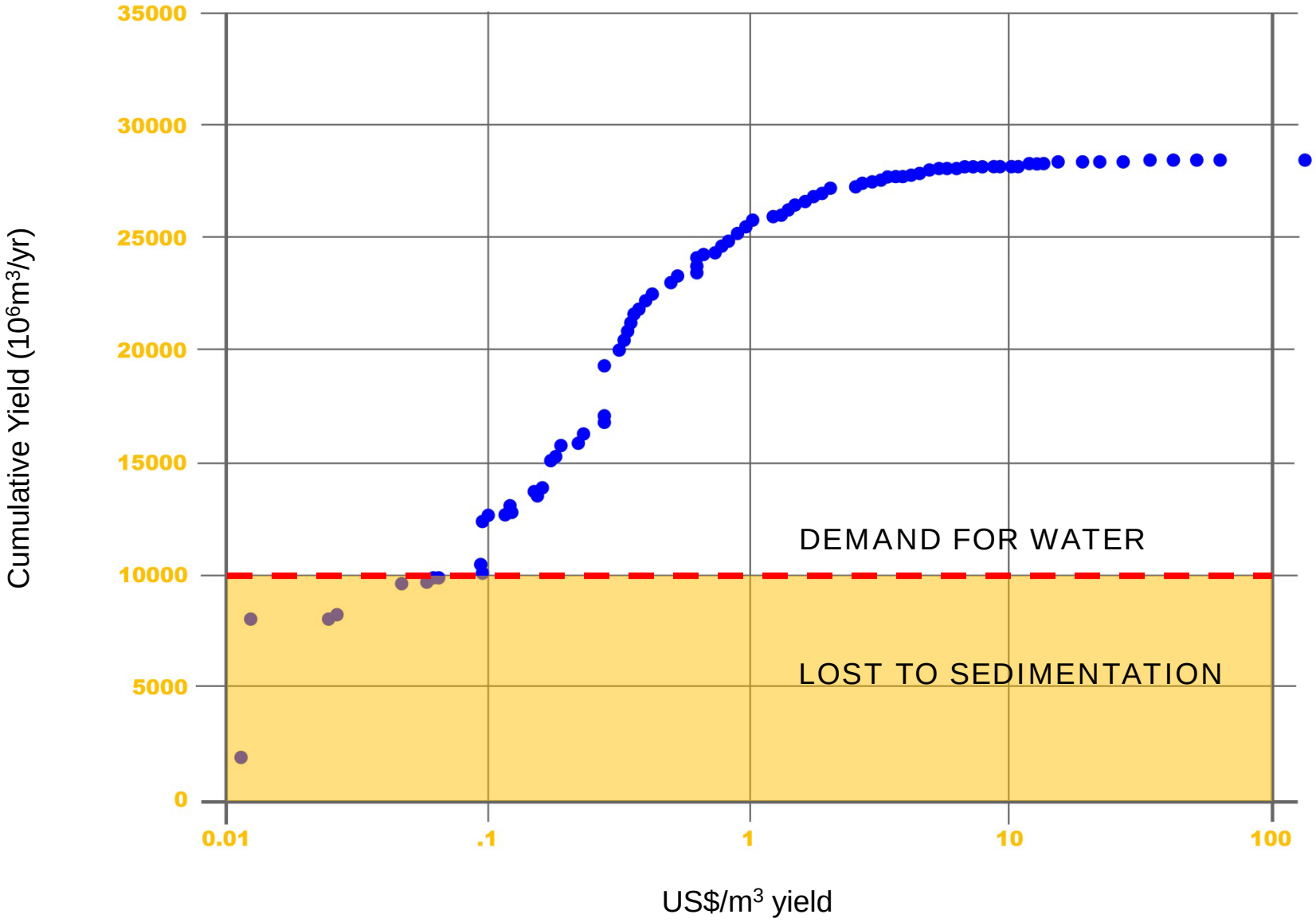
DUAL NATURE OF RESERVOIR STORAGE

RENEWABLE OR EXHAUSTIBLE – DEVELOPER'S CHOICE

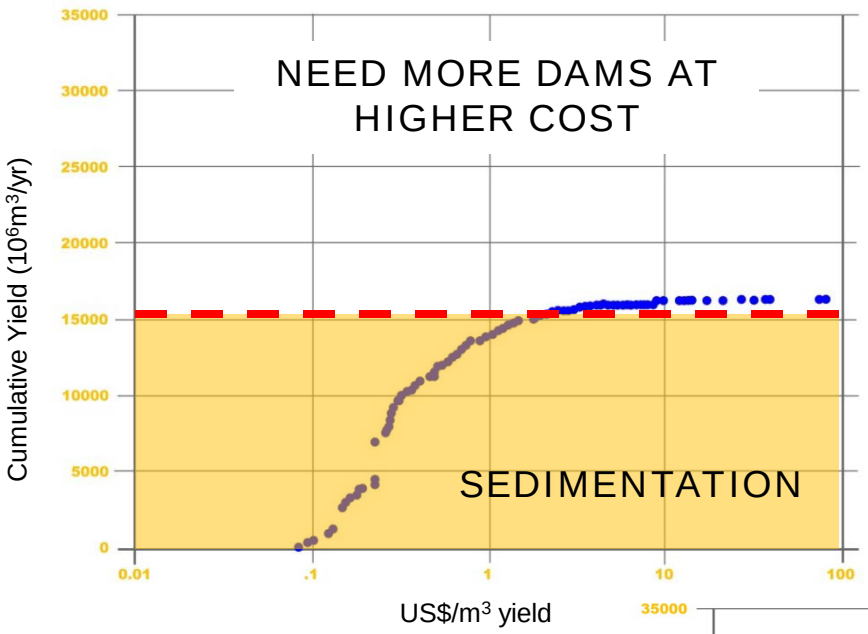
LIMITED NUMBER OF DAM SITES

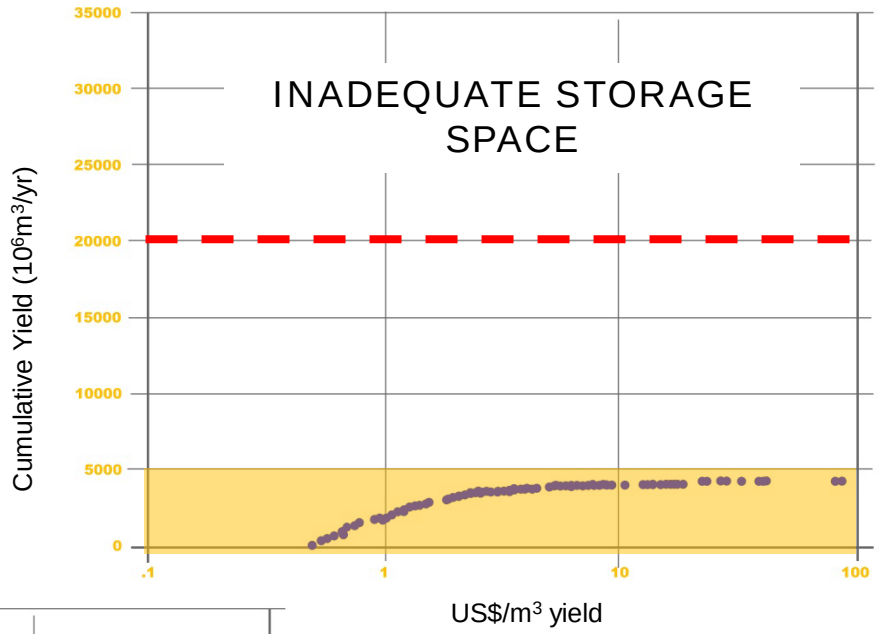
CONSEQUENCE OF CURRENT DEVELOPMENT POLICY

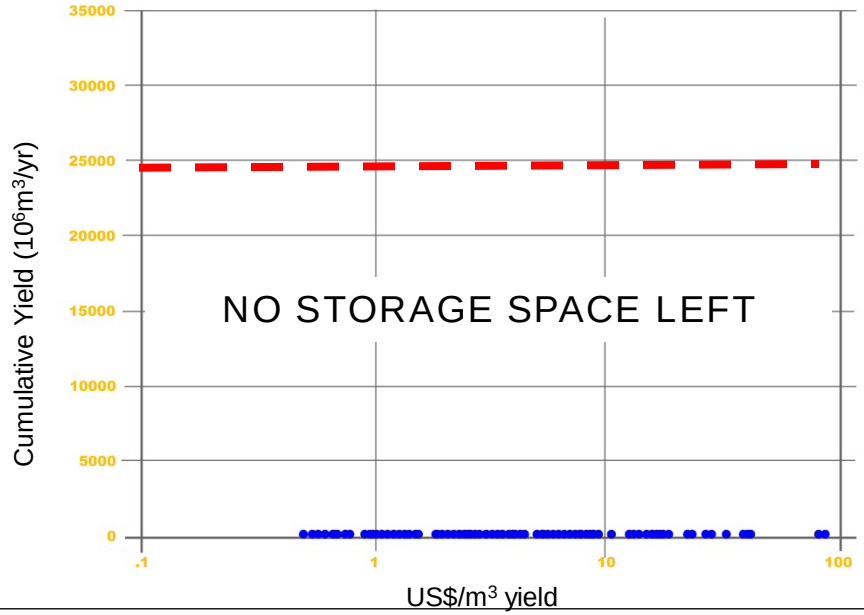


FUTURE GENERATIONS

CONSEQUENCE OF CURRENT DEVELOPMENT POLICY







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MAKING THE RIGHT CHOICE: RENEWABILITY

RESERVOIR SEDIMENTATION MANAGEMENT OPTIONS

Manage amount of sediment generated by the catchment

Upstream Management

- Check Dams
- Forestation

Allow sediment inflows to pass through or around the reservoir

Sediment Routing

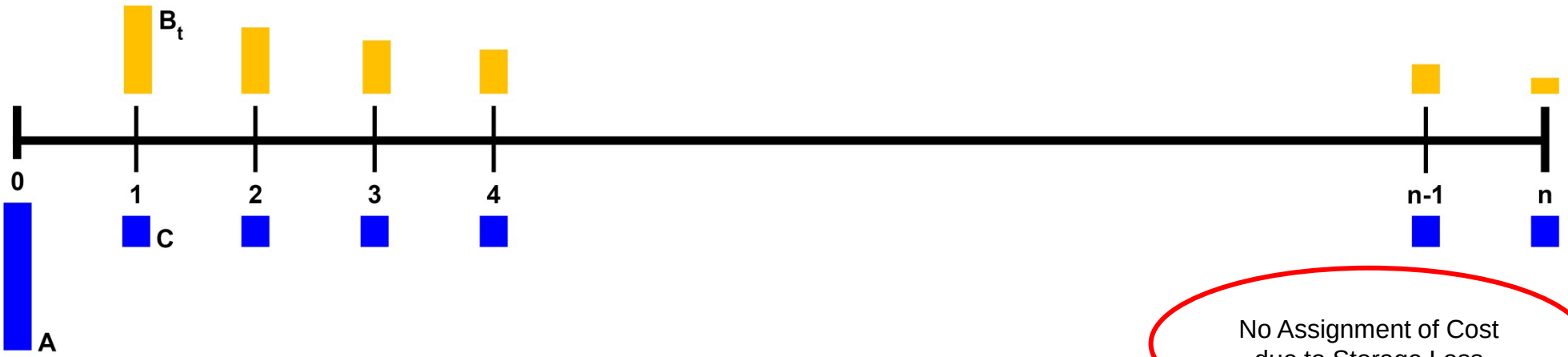
- Sluicing
- Density Current Venting
- Bypass

Remove sediment which accumulates in the reservoir

Sediment Routing

- Dredging
- Excavation
- Hydro-suction
- Pressure Flushing
- Drawdown Flushing

CURRENT ECONOMIC ANALYSIS APPROACH



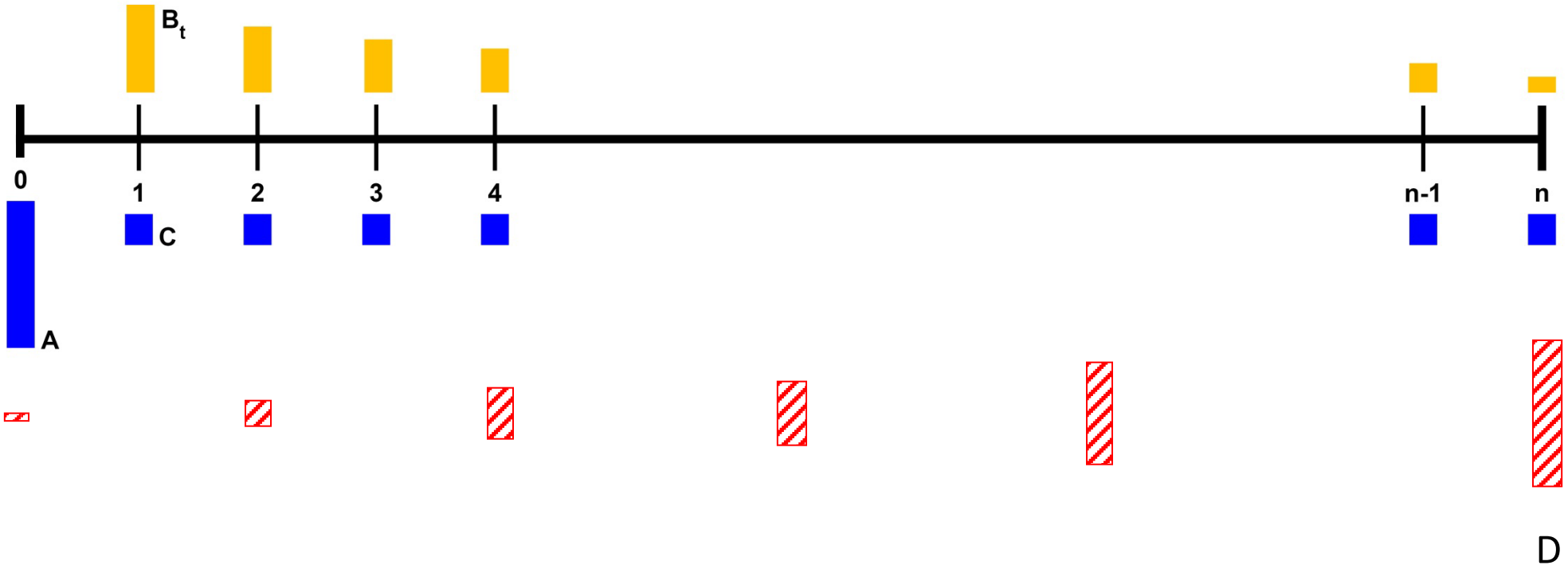
No Assignment of Cost due to Storage Loss

$$NPV = \sum_{t=0}^{n} B_t \cdot d^t - A - \sum_{t=0}^{n} C \cdot d^t$$

$$d = \frac{1}{(1+r)}$$

CURRENT ECONOMIC ANALYSIS APPROACH

CONVENTIONAL REASONING FOR IGNORING LOSS

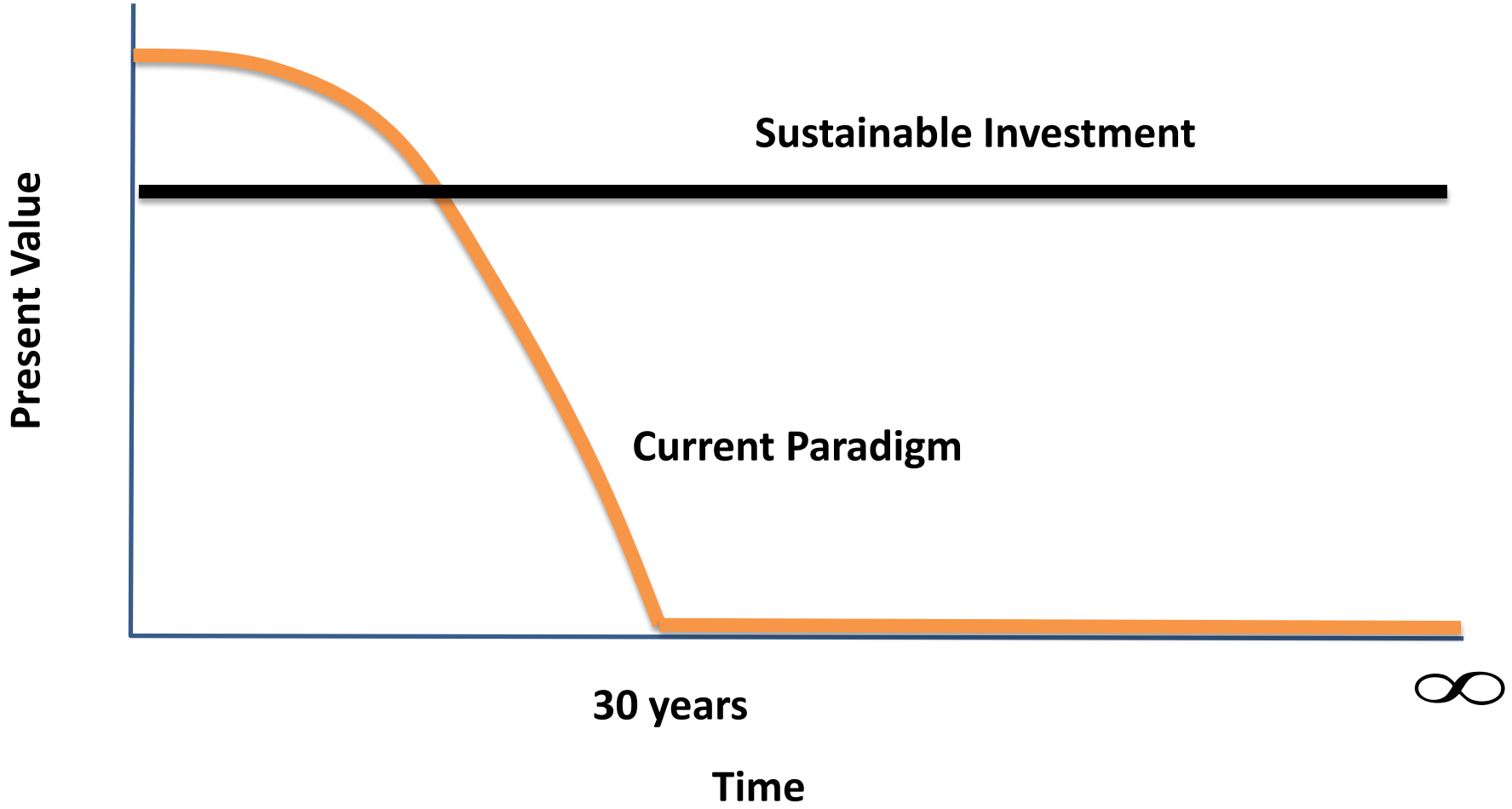


PV(D) <<< D

$$NPV = \sum_{t=0}^{n} B_t \cdot d^t - A - \sum_{t=0}^{n} C \cdot d^t$$

CURRENT ECONOMIC ANALYSIS APPROACH

WHICH INVESTMENT SCHEME DO YOU PREFER?

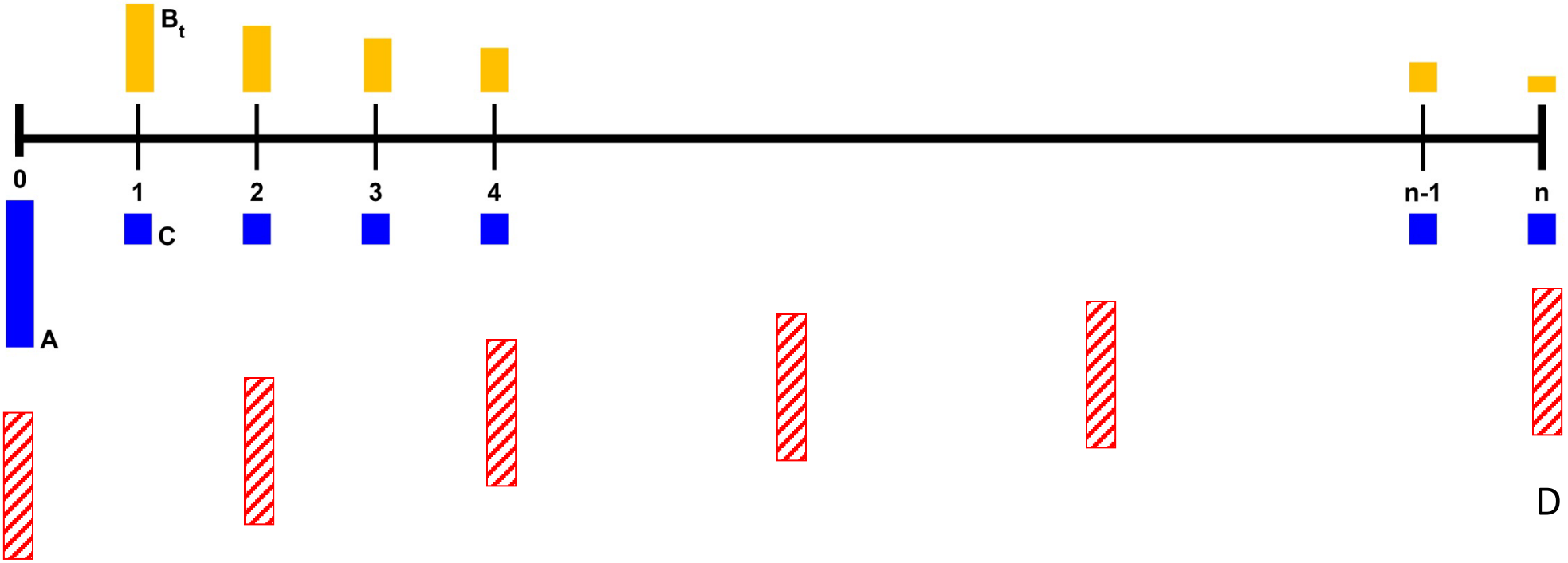


Gregory L. Morris – personal communication

CORRECT ECONOMIC ANALYSIS APPROACH

HOTELLING PRINCIPLE

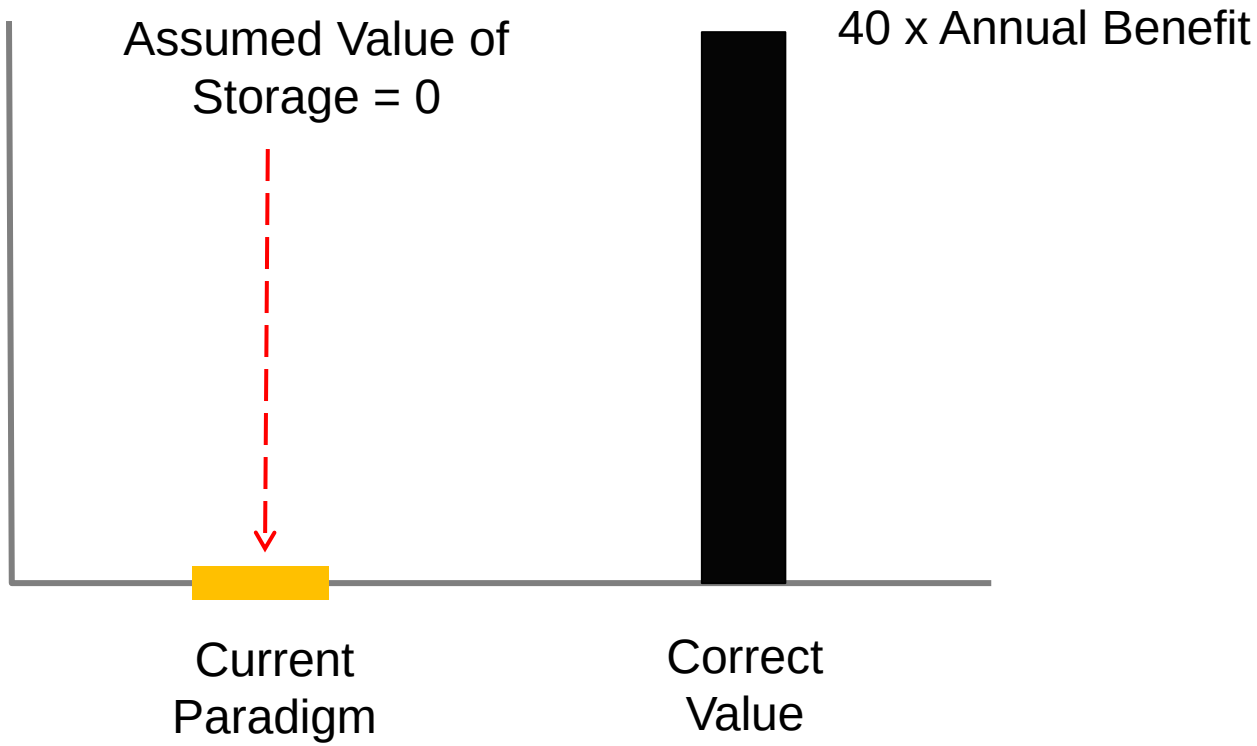
- Hotelling: Price of an Exhaustible Resource increases with the discount rate (i.e. Discounted value does not change)



PV = D

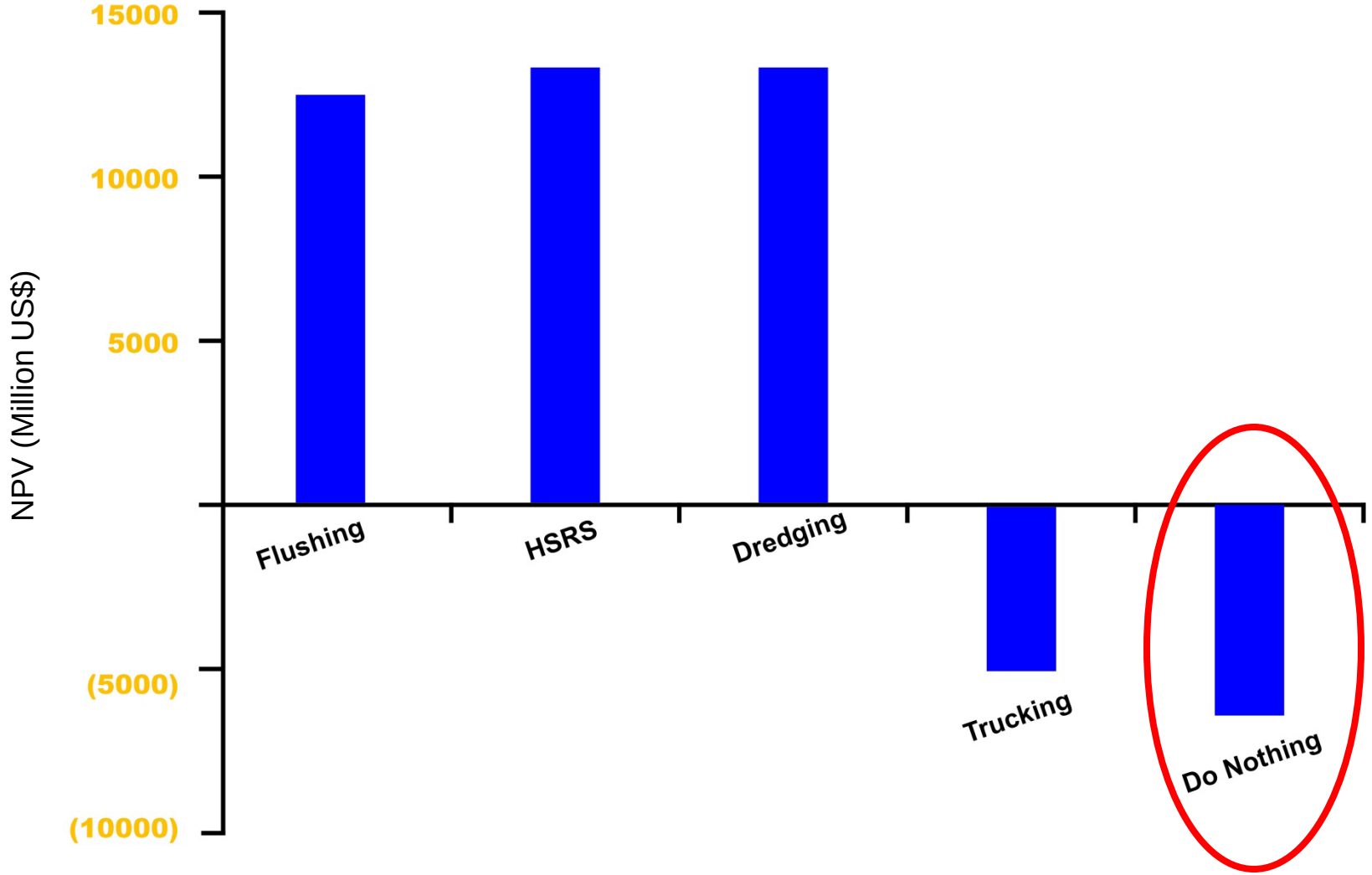
$$NPV = \sum_{t=0}^{n} B_t \cdot d^t - A - \sum_{t=0}^{n} C \cdot d^t - D$$

VALUE OF RESERVOIR STORAGE SPACE



ECONOMIC VIABILITY

HOTELLING PRINCIPLE



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GUIDING PRINCIPLES

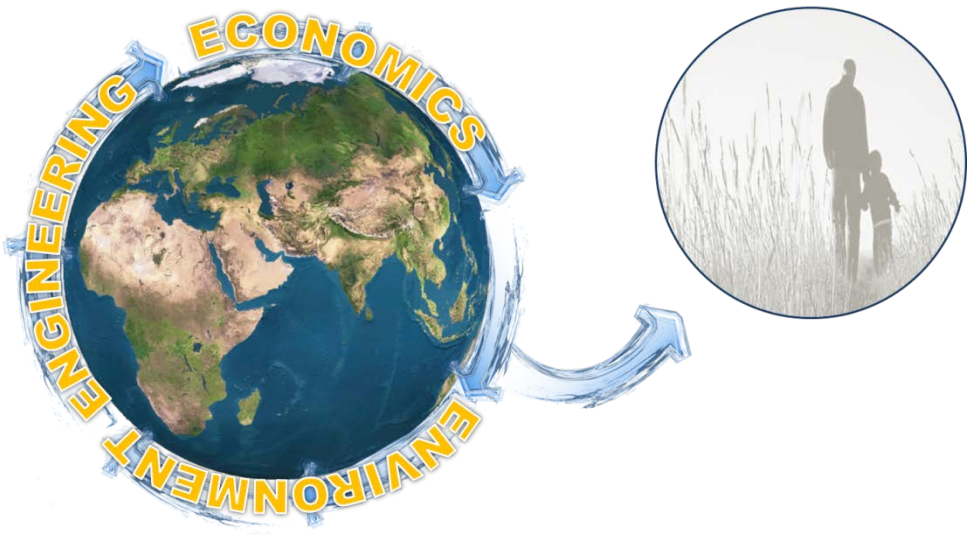
- Sustainable Development is accomplished

  if

- Intergenerational Equity is Created

  through

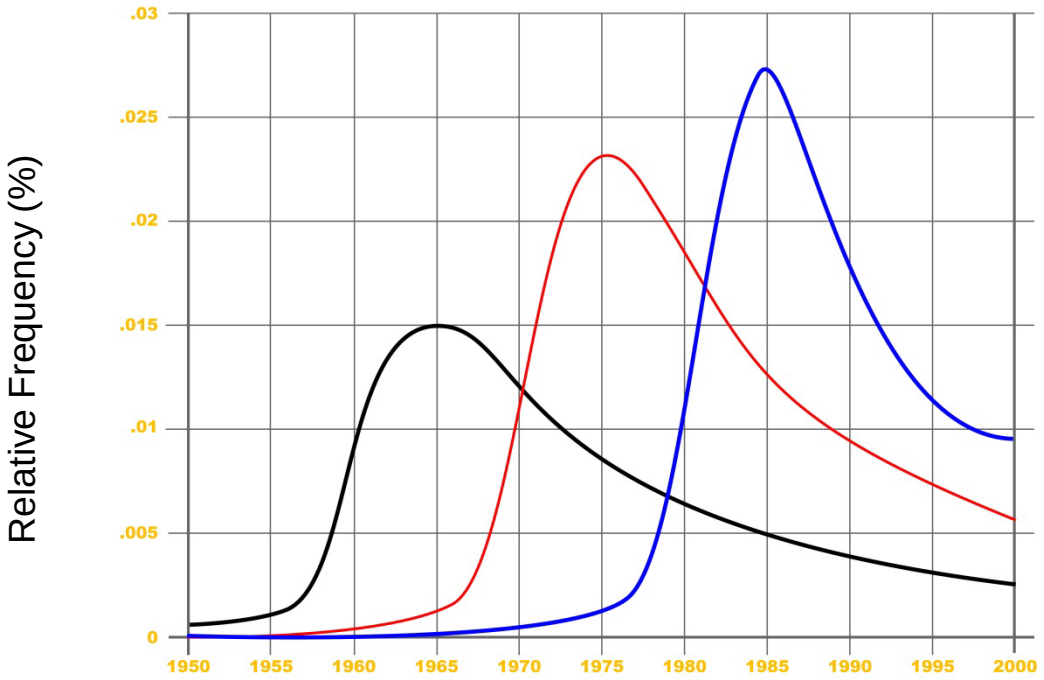
- Harmonizing the Engineering, Economic and Environmental Requirements of Projects



CREATING INTERGENERATIONAL EQUITY

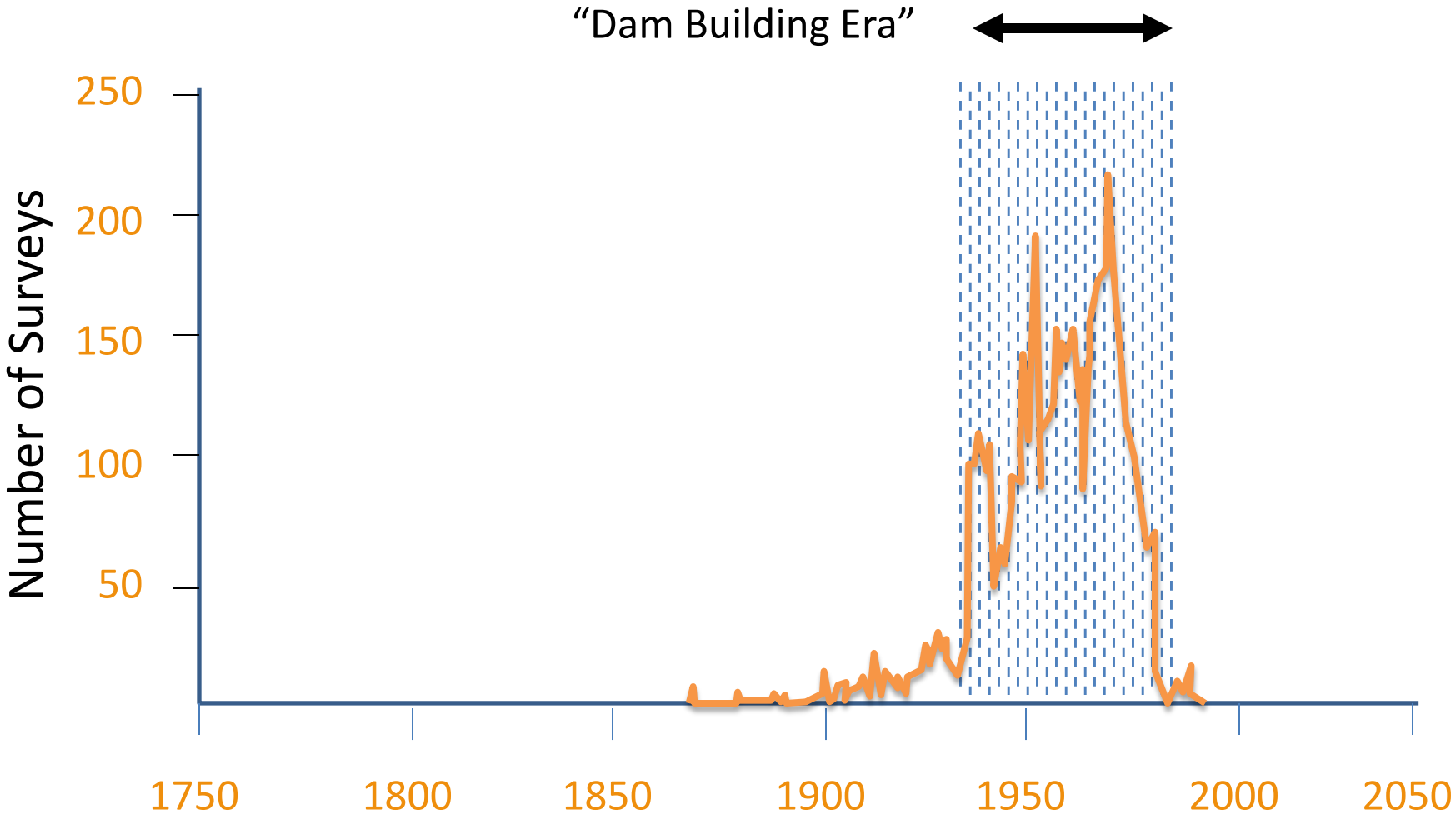
NEED FOR REGULATION

n-grams for the words “1960”, “1970” and “1980”



- Man is selfish, self-centered and focused on the present
- Policy and Government Regulation Required to Ensure Sustainable Development

RESERVOIR RESURVEYS IN US DOES THIS MAKE SENSE??

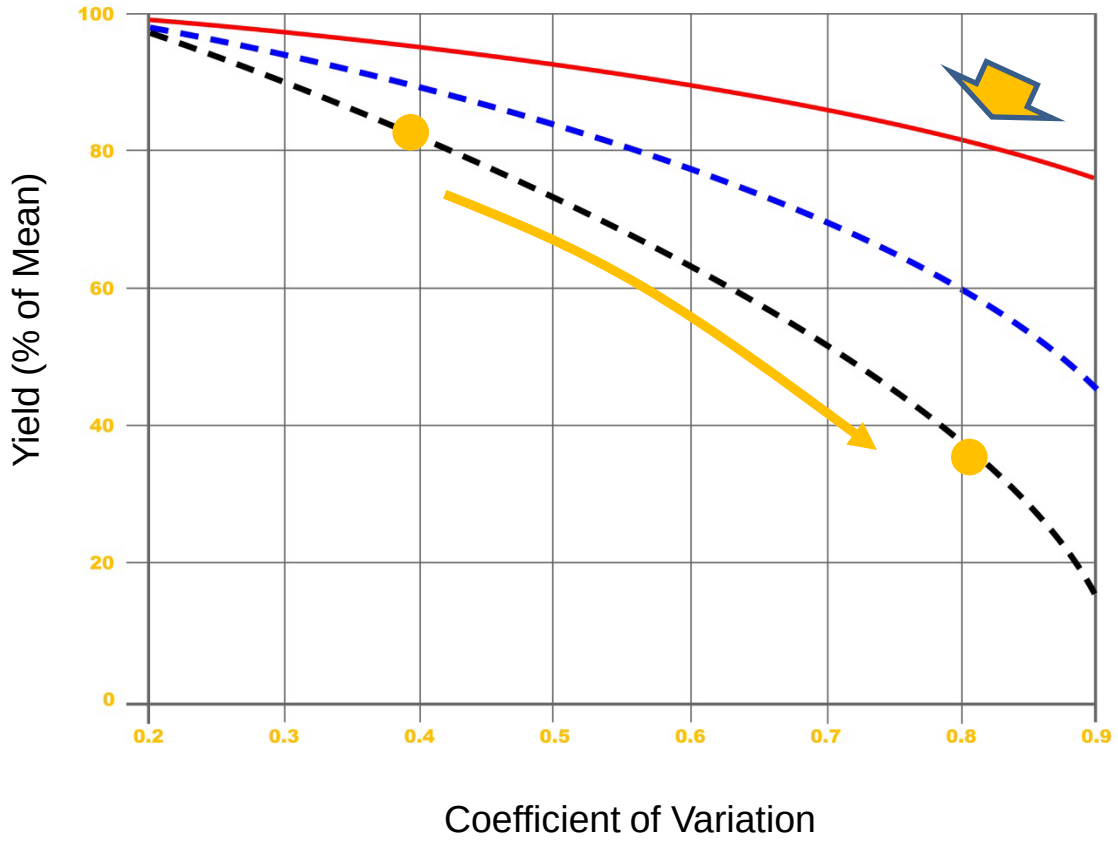


We cannot solve the problem if we do not know its magnitude

RECOGNIZE IMPORTANCE OF STORAGE

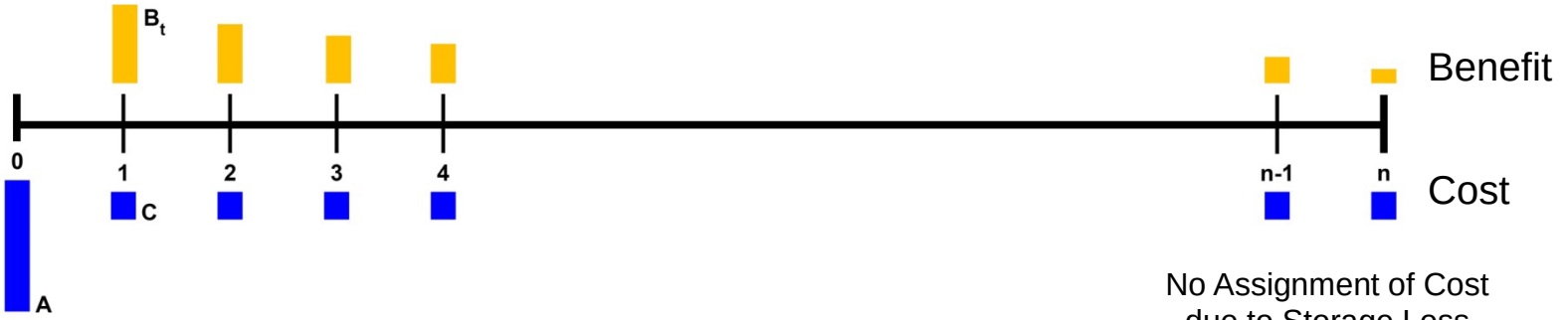
ACKNOWLEDGE CLIMATE CHANGE EFFECTS

Reliability = 99%



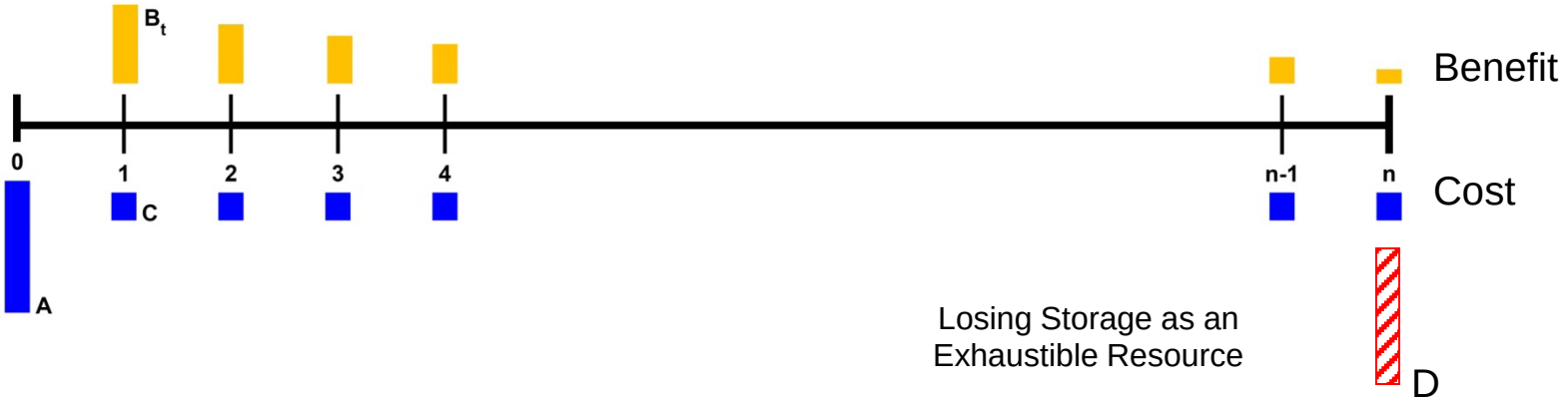
Robust Infrastructure

ACKNOWLEDGE DUAL NATURE OF STORAGE ECONOMIC ANALYSIS



No Assignment of Cost due to Storage Loss

INCORRECT



Losing Storage as an Exhaustible Resource

CORRECT

Hotelling Principle

DESIGN AND OPERATION

PARADIGM SHIFT REQUIRED

Planning & Design

Construction

O&M

Disposal

Conventional Design Life Approach

DESIGN AND OPERATION

NEW PARADIGM

Planning & Design

Construction

O&M

Refurbishment

Sediment Removal

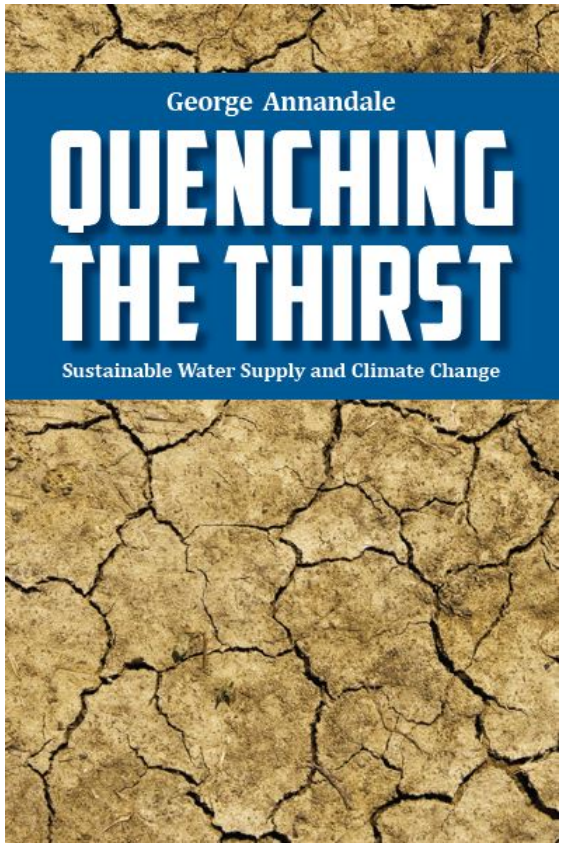
Preferred Approach: Life-Cycle Management Approach

CONCLUSIONS

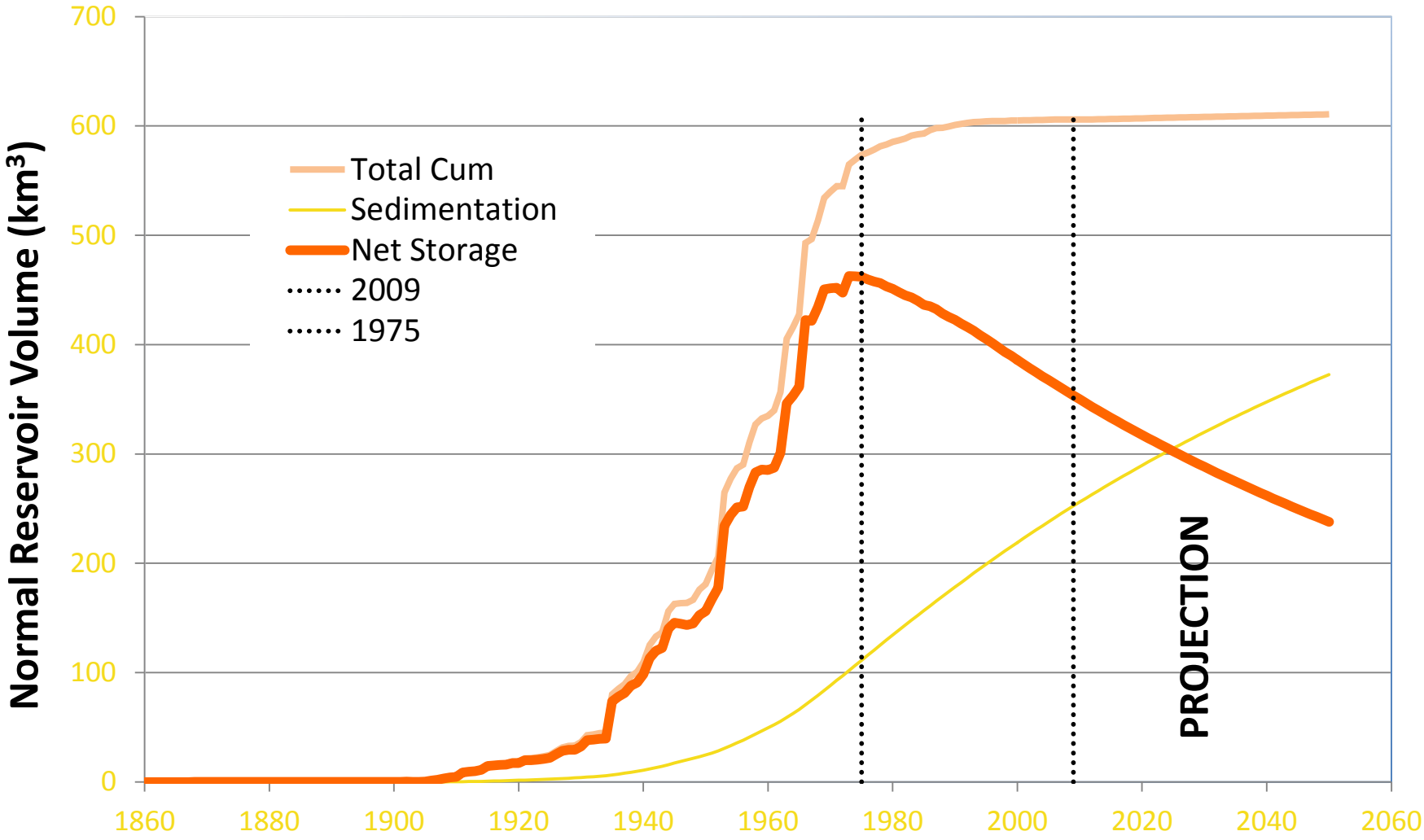
- Creation of Intergenerational Equity:
  - Central Theme of Sustainable Development
- Water Source Selection
  - River Water Preferred
  - Groundwater – Non-sustainable
- Reliable Water Supply
  - Need Storage
  - Need for Storage will Increase with Climate Change
- Dual Nature of Storage Space
  - Exhaustible:
    Loss of Storage to Reservoir Sedimentation
  - Renewable: :
    Implement Reservoir Sedimentation Management
- Policy
  - Regulate Need for Sustainable Development
    - Creation of Intergenerational Equity
    - Harmonize Engineering, Economic and Environmental Project Requirements
  - Resource Selection
    - River Water or Groundwater
  - Recognize Importance of Storage
    - Allow for Effects of Climate Change
    - Resurveys of Reservoirs
  - Regulate Correct Implementation of Economic Analysis
    - Hotelling Principle
  - Regulate Life Cycle Management Approach / Importance of Sediment Management
    - Incorporate Sediment Management Technology in All Dam Designs
    - Sustainably Manage Existing Infrastructure

REFERENCE

- Annandale, G.W. 2013. ***Quenching the Thirst: Sustainable Water Supply and Climate Change***, CreateSpace Independent Publishing Platform, Charleston, SC.
- www.amazon.com/author/georgeannandale



US STORAGE
ALL LARGE DAMS



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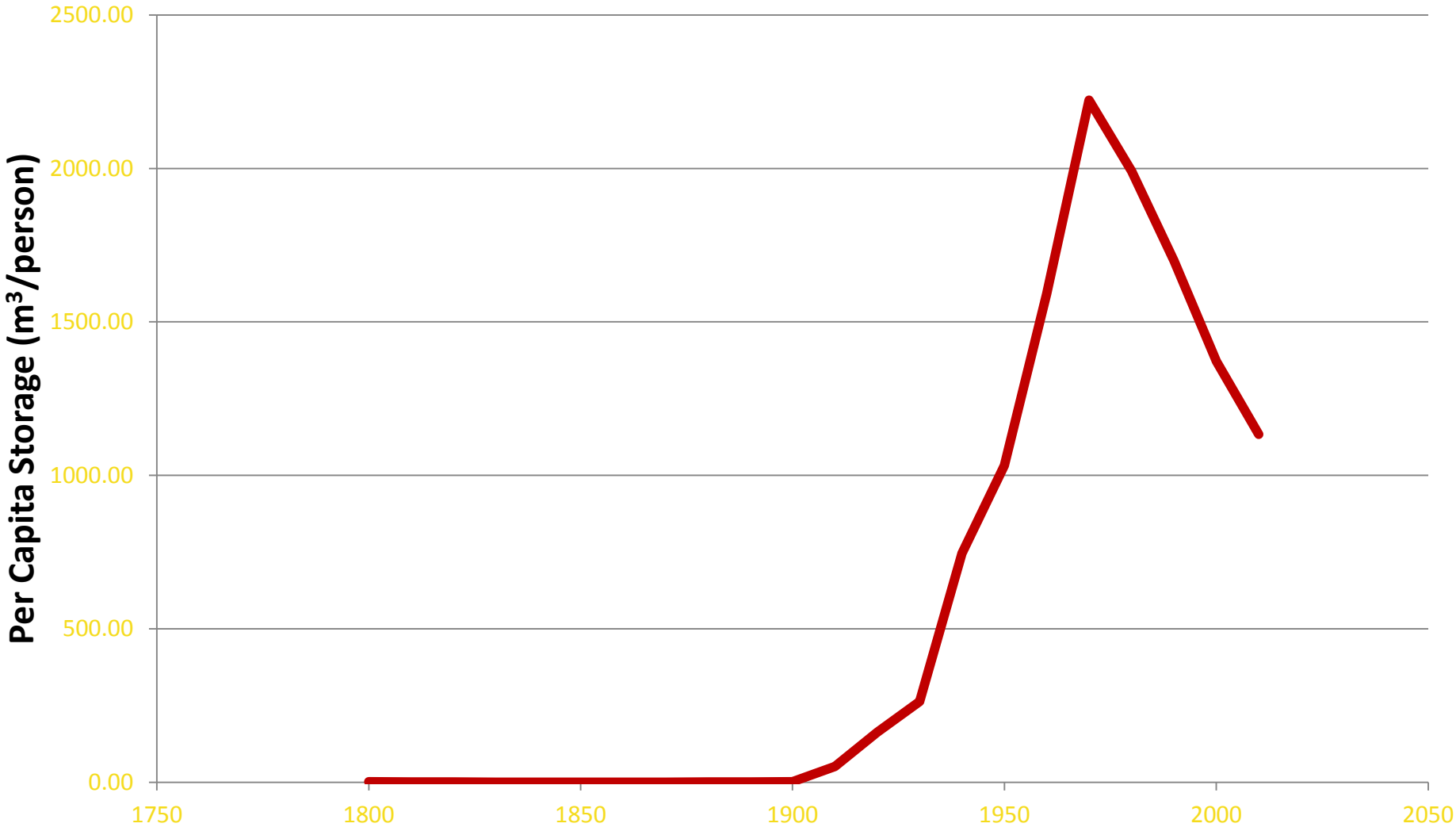
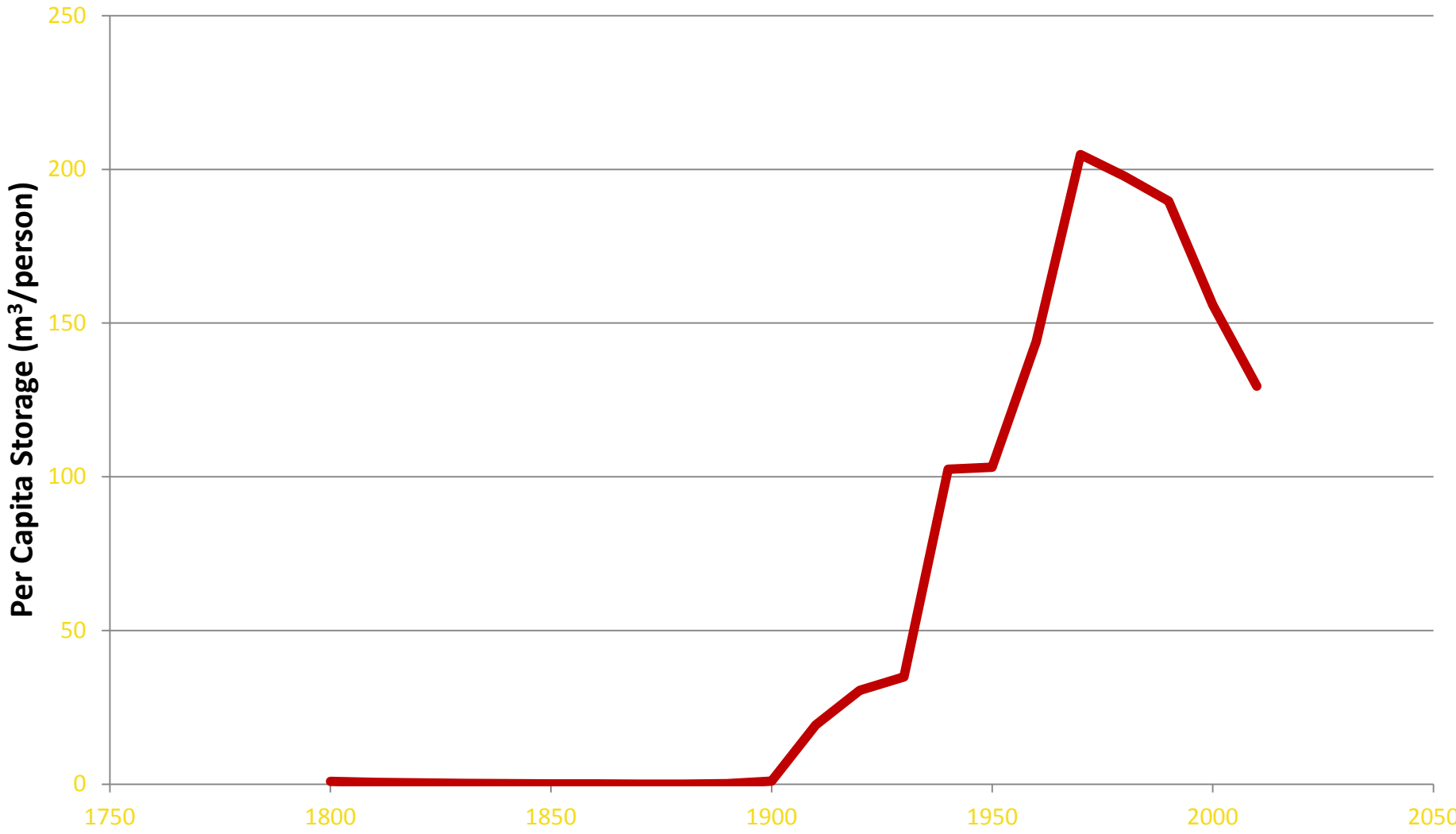
US STORAGE PER CAPITA (ALL LARGE DAMS)



US STORAGE
PER CAPITA (WATER SUPPLY & IRR.)



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