

# RIVERWARE MODEL OF THE EASTERN NILE REGION



RiverWare User Group Conference  
Boulder, Colorado  
August 26-27, 2013



WATER  
BALANCE  
CONSULTING

Kevin Wheeler, P.E.

# Acknowledgements

Big Thanks to:

- John Carron
- Steve Setzer
- Taylor Adams
- Edie Zagona
- Gwen Miller
- David Neumann
- Mitch Clement



(Pretty much everyone at CADSWES)

# Agenda Topics

Item  
1

The Context of the Nile

Item  
2

Eastern Nile RiverWare Model

Item  
3

Development Scenario Examples

Item  
4

Future Applications

# Nile Basin Countries







# A Valid Comparison?

Colorado River Basin	Nile River Basin
40 Million People	238 Million
7 States + 2 Countries	11 Countries
18.5 BCM/year	82.5 BCM/year
462 m <sup>3</sup> /person	347 m <sup>3</sup> /person
#1 Use = Agriculture	#1 Use = Agriculture

Trans-boundary Management Agreements	
1922 - Colorado Compact	No Basin-wide Agreement
1944 – USA/Mexico Treaty	
1948 - Upper Basin Compact	

# Water Allocation? - 1902

1902 – “Treaty between Ethiopia and the United Kingdom, Relative to the Frontiers between the Anglo-Egyptian Sudan, Ethiopia, and Eritrea”

Emperor Menelik II of Ethiopia “engages himself towards the Government of His Britannic Majesty not to construct, or allow to be constructed, any work across the Blue Nile, Lake Tsana, or the Sobat which would arrest the flow of their waters into the Nile, except in agreement with His Britannic Majesty’s Government and the Government of the Sudan”



Ethiopia:

- ✓ Amharic and English Versions are Different
- ✓ Never Ratified by any Government Organ

# Water Allocation? - 1929

## “1929 Nile Waters Agreement”

Between British East African Colonies  
Egypt vs. Kenya, Uganda, Tanganyika, Sudan

“Except with the prior consent of the Egyptian Government, no irrigation works shall be undertaken nor electric generators installed along the Nile and its branches nor on the lakes from which they flow if these lakes are situated in Sudan or in countries under British administration which could jeopardize the interests of Egypt either by reducing the quantity of water flowing into Egypt or appreciably changing the date of its flow or causing its level to drop.”

DF



# Water Allocation? - 1959

“1959 Nile Waters Agreement between the United Arab Republic and the Republic of the Sudan for the Full Utilization of the Nile Waters”

Established the Total Annual Flow at Aswan = 84 BCM

- 55.5 BCM to Egypt
- 18.5 BCM to Sudan
- 10.0 BCM for Evaporation at Lake Nassar



Ethiopia, Uganda, Kenya, Tanzania, Rwanda, Burundi, DRC:

- ✓ Completely Rejected
- ✓ “Reasonable and Equitable Use” – 1966 Helsinki Rules

DRC  
Uganda  
Rwanda  
Burundi  
Kenya  
Tanzania

# Infrastructure

1902 - Low Aswan Dam (Egypt)

1925 - Sennar Dam (Sudan)

1937 - Jebel Aulia Dam (Sudan)

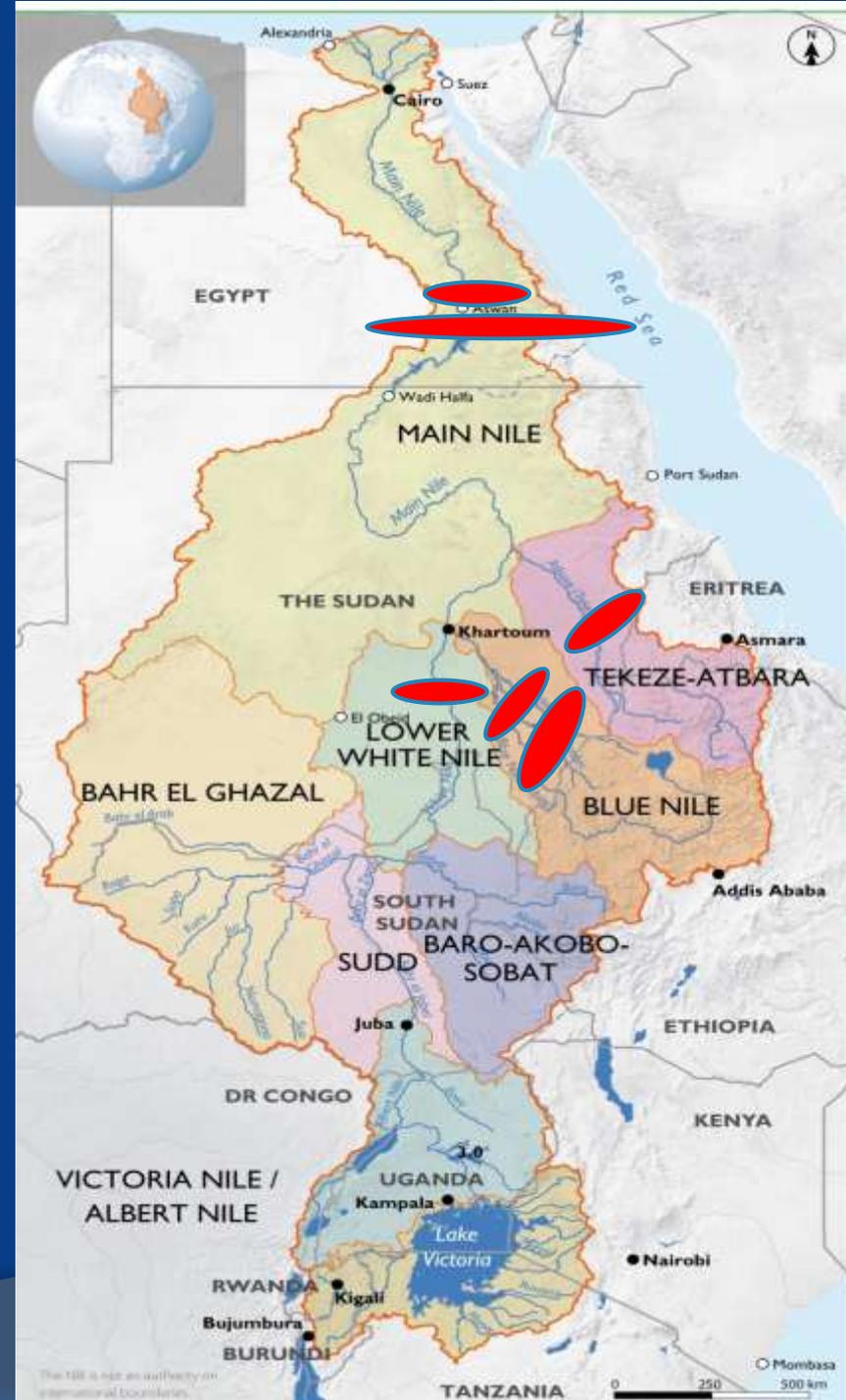
1959 Egypt-Sudan Treaty

1964 - High Aswan Dam (Egypt)

1965 - Khashm El Girba (Sudan)

1967 - Rosaries Dam (Sudan)

1964 – USBR Study “Land and Water Resources of the Blue Nile Basin”



# Infrastructure

## Ethiopia

2009 - Tekeze Dam

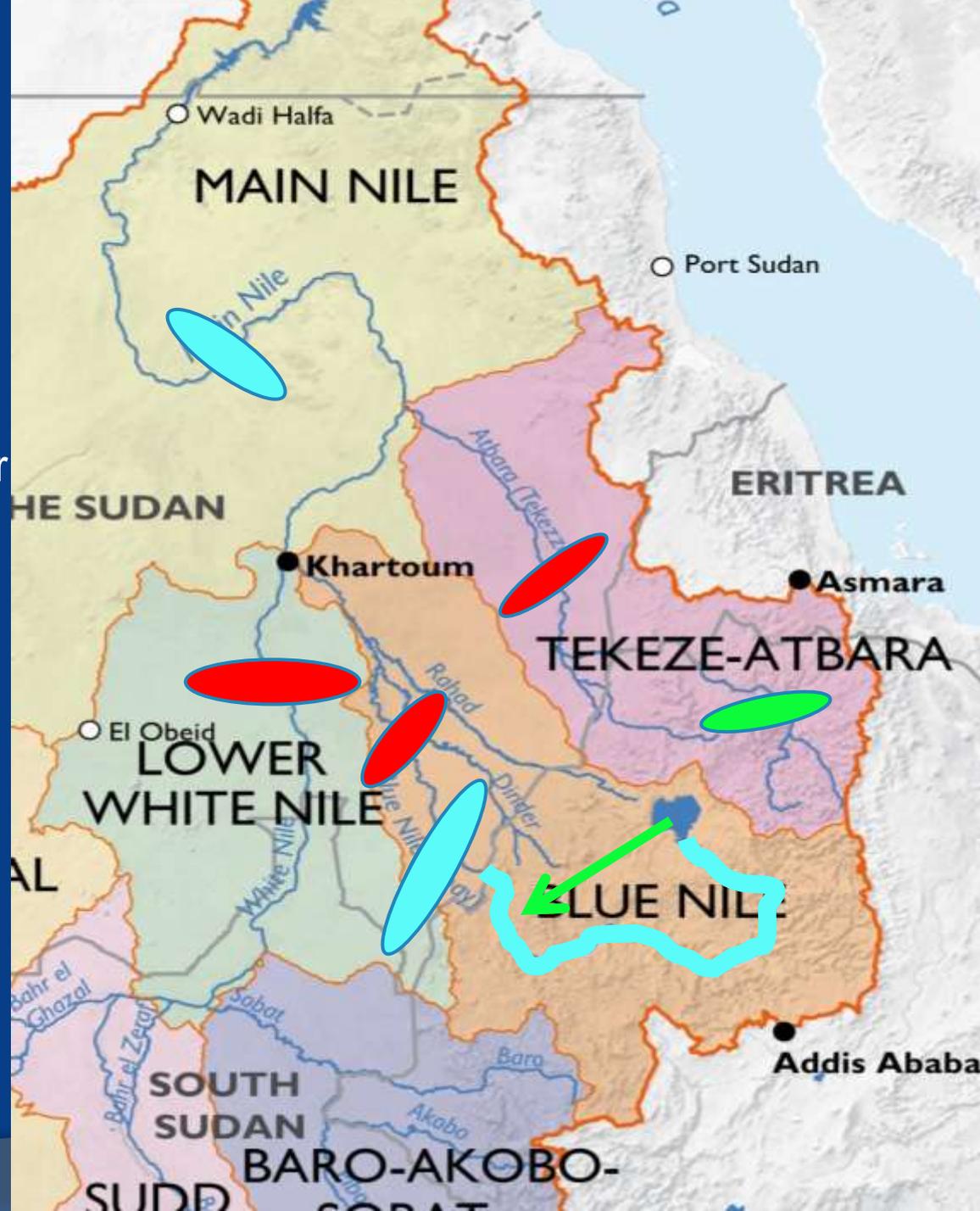
2010 - Tana-Beles Hydropower Diversion

1964 – USBR Study “Land and Water Resources of the Blue Nile Basin”

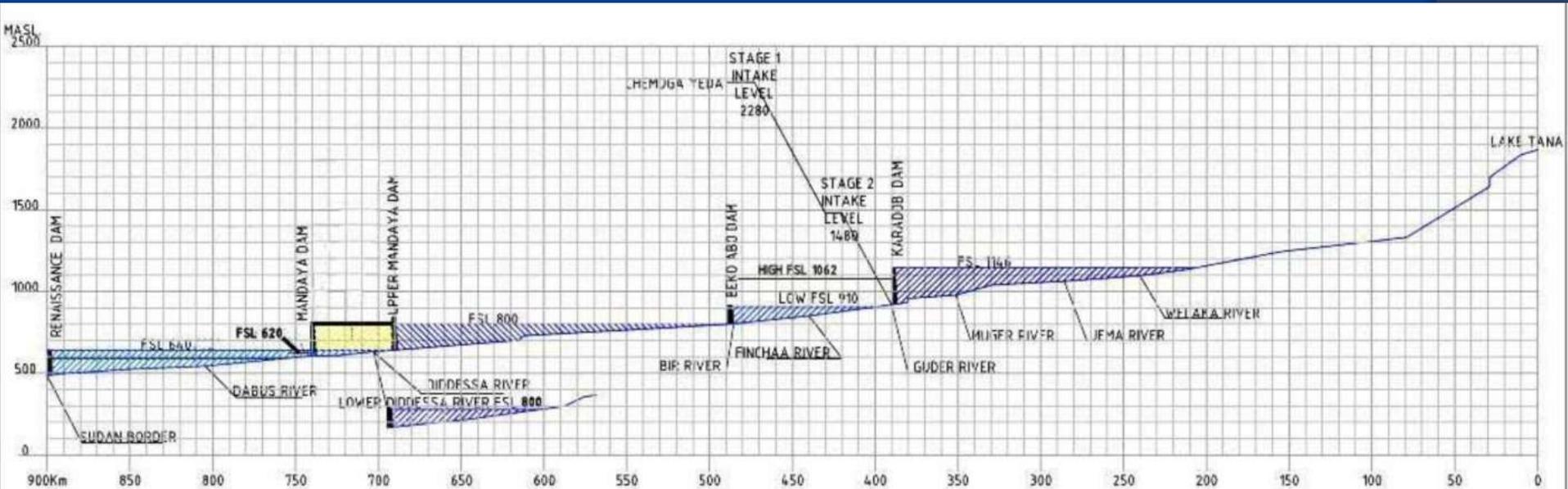
## Sudan

2009 – Merowe Dam

2012 – 10 m Heightening of Rosaries Dam



# Ethiopian Blue Nile Cascade Plans



27-10-2010

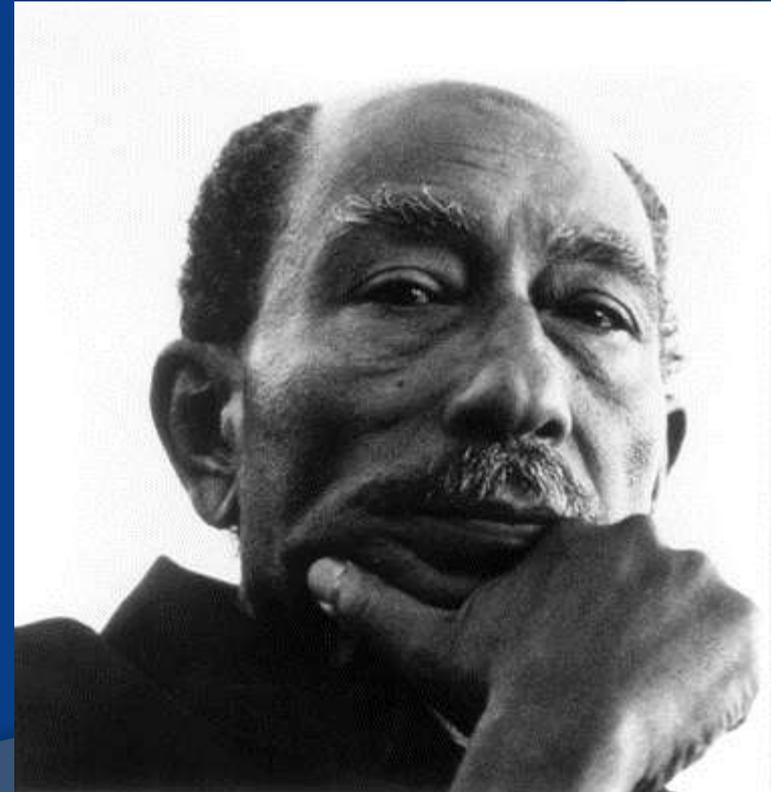
Changes	Appr.	Check	Drawn	Date	Sheet
MINISTRY OF WATER RESOURCES					
PRELIMINARY STUDY OF THE BEKO-ABJO MULTIPURPOSE PROJECT					
ABAY RIVER BASIN CASCADE					
DEVELOPMENT OPTIONS PROFILE					
Drawing no: A-01 Project no:				Date drawn: _____ Date checked: _____ Date approved: _____ Scale: AS SHOWN Revision: _____ Drawn by: _____ Checked by: _____ Approved by: _____	

# Historical Egyptian Position

“The only matter that could take Egypt to war again is water.”

“We depend upon the Nile 100 percent in our life, so if anyone, at any moment, thinks of depriving us of our life we shall never hesitate to go to war.”

Egyptian President Anwar Sadat, 1979



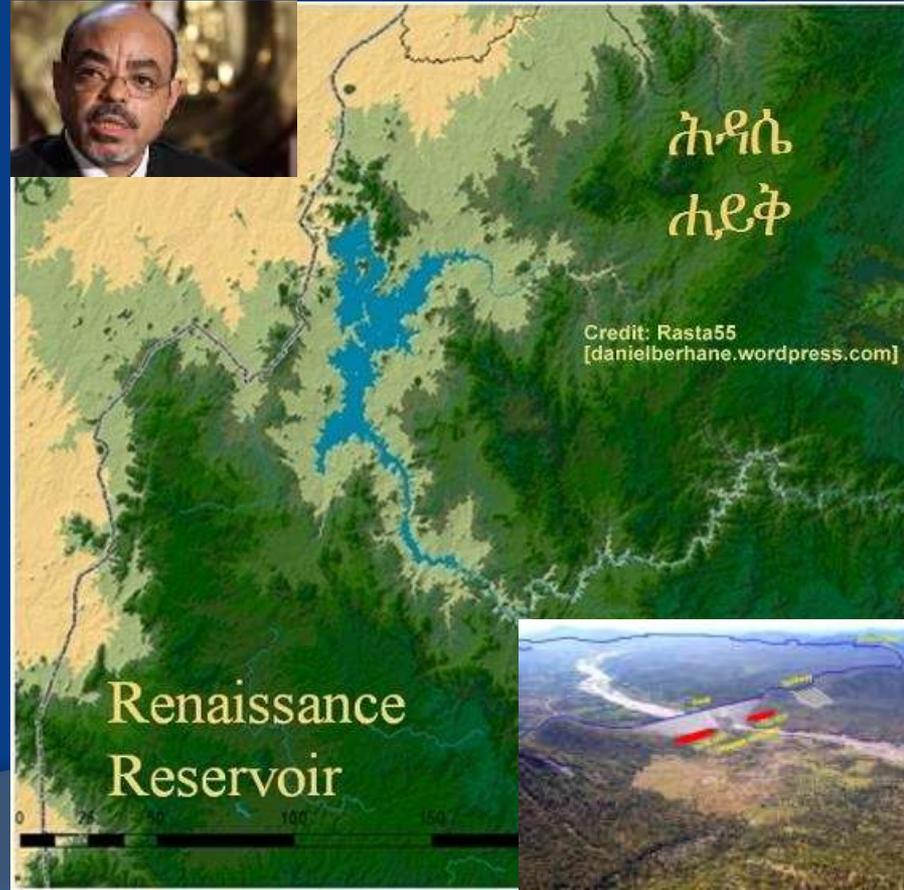
# 1999 Nile Basin Initiative

- ◉ Shared vision of ‘sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile Basin water resources’
- ◉ Cooperative Framework Agreement (CFA)
  - Signed by Ethiopia, Rwanda, Tanzania, Uganda, Kenya, Burundi
  - Egypt wants an addition to “Not to adversely affect the water security and current uses and rights of any other Nile Basin”



# March 2011

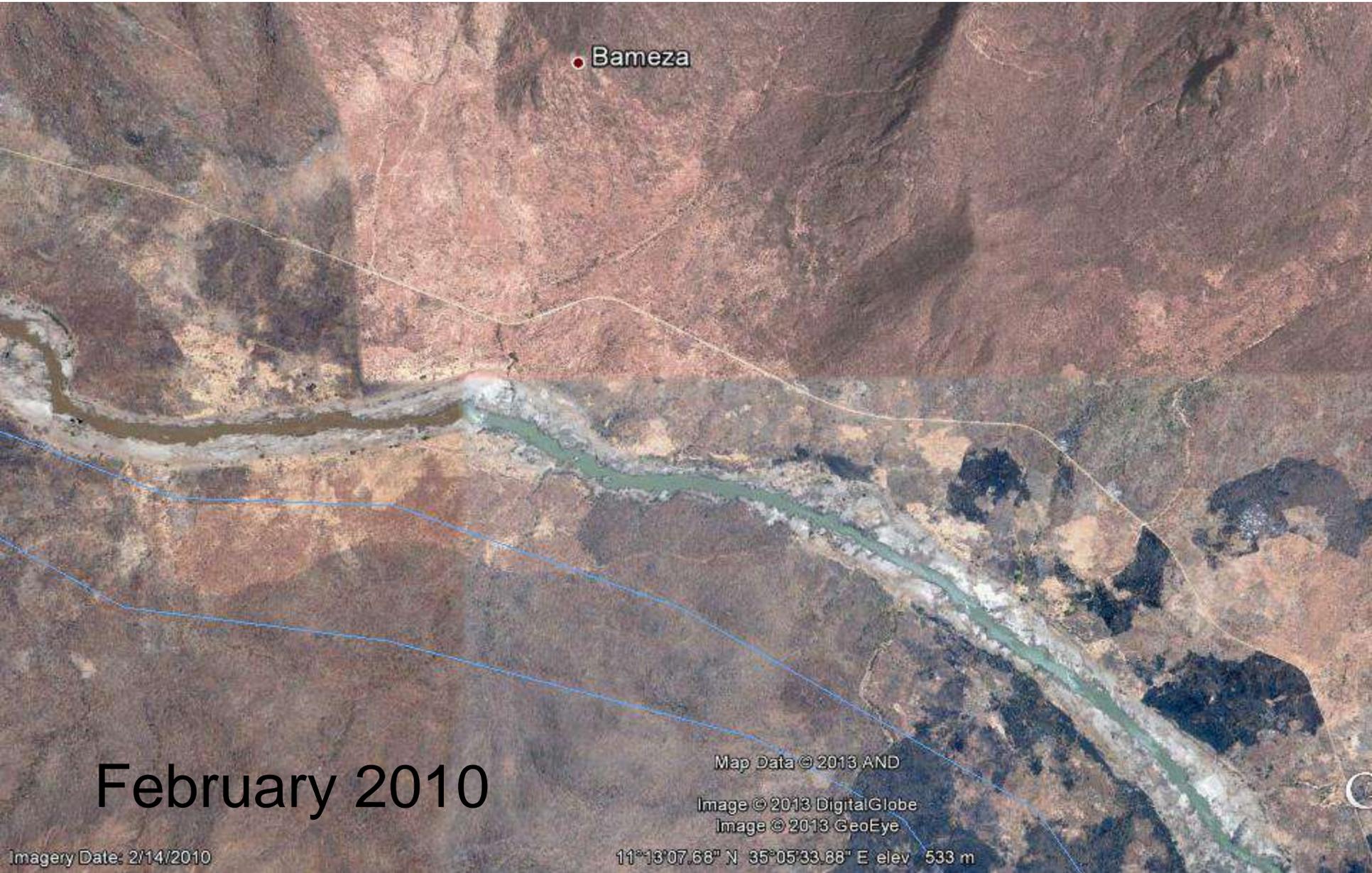
PM Meles Zenawi Announced  
The Grand Ethiopian  
Renaissance Dam (GERD)



# Grand Ethiopian Renaissance Dam

- ⦿ 6,000 MW Capacity
- ⦿ 74 BCM Storage Volume
  - 150% of Average Annual Flow at Dam Site
- ⦿ 15,000 GWH of Additional Energy
- ⦿ 4 to 5 times current Ethiopian Production
- ⦿ Sold to Sudan, Kenya, South Sudan, Egypt?
  
- ⦿ No Plans for Diversion

# Grand Ethiopian Renaissance Dam



• Bameza

February 2010

Map Data © 2013 AND

Image © 2013 DigitalGlobe

Image © 2013 GeoEye

11°13'07.66" N 35°05'33.88" E elev 533 m

Imagery Date: 2/14/2010

# Grand Ethiopian Renaissance Dam



• Bameza

May 2012

Map Data © 2013 AND

Image © 2013 DigitalGlobe

Image © 2013 GeoEye

11°13'07.66" N 35°05'33.88" E elev 538 m

Imagery Date: 5/28/2012

# Funding the Dam - \$4.8B –

## 15%GDP

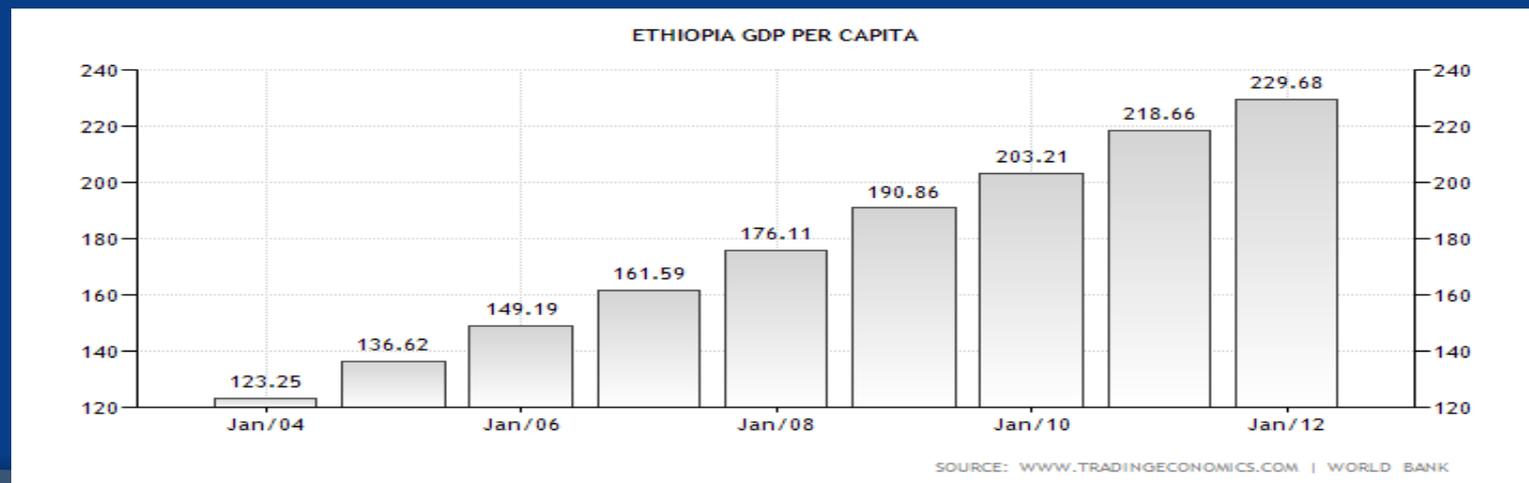
⦿ Telecom – State Controlled Telecommunications

⦿ All citizens contributing 1 month salary

- Each year for 5 years!

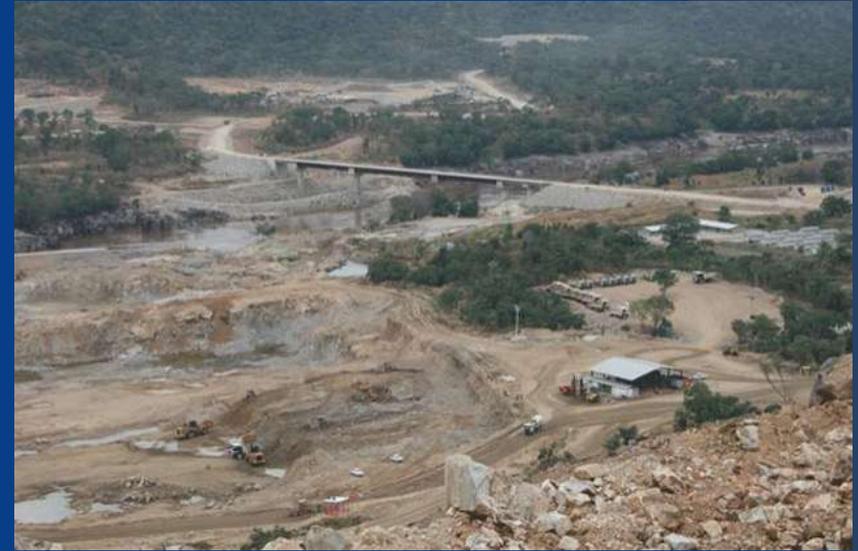
⦿ Public Bonds

“PURCHASE THE BOND AND PUT YOUR FINGER PRINT IN THE CONSTRUCTION OF THE GRAND ETHIOPIAN RENAISSANCE DAM ON THE ABAY RIVER!”



# Construction of the GERD

- Unilateral Decision
- Outside of NBI
- Design Not Public
- EIA Not Public
- No Operating Agreements



CREDIT: EEPCo



CREDIT: William George



CREDIT: Tiksa Negeri

# Potential for Water Wars?

- ⦿ Water conflict analysis (Wolf)
- ⦿ Hydro-hegemony theory (Zeitoun)
- ⦿ No Military Action according to statements by Egypt

# The Politics

**BBC** Sign in News Sport Weather iPlayer TV Ra

## NEWS AFRICA

Home World UK England N. Ireland Scotland Wales Business Politics Health Education Sci/Env  
Africa Asia Europe Latin America Middle East US & Canada

4 June 2013 Last updated at 15:37

### Egyptian politicians caught in on-air Ethiopia dam gaffe

By Ahmed Maher  
BBC News

**Egyptian politicians are embarrassed after being caught suggesting hostile acts against Ethiopia to stop it from building a dam across the Blue Nile.**

They were inadvertently heard on live TV proposing military action at a meeting called by President Mohammed Morsi.

Ethiopia last week started diverting the flow of the river in preparation for the \$4.2bn hydroelectric dam.

The Blue Nile is one of two major tributaries of the Nile.

On completion, the Grand Ethiopian Renaissance Dam would be Africa's largest.

**Related Stories**

Ethiopia diverts Blue Nile for dam

4 June 2013 Last updated at 15:37

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AP

- Egypt Government Rejects a Military Solution
- International Panel of Experts
  - 2 Egyptian, 2 Sudanese, 2 Ethiopian, 4 International Experts
  - Findings Complete
    - 'No Significant Impact'
    - 'Needs More Studies'
    - .... still not released to the public
- How will the GERD Impact Downstream Countries?
  - How will this be measured?
  - What will happen if there is?

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# Models in Use

RibaSim

MIKE Basin

RiverWare

WEAP

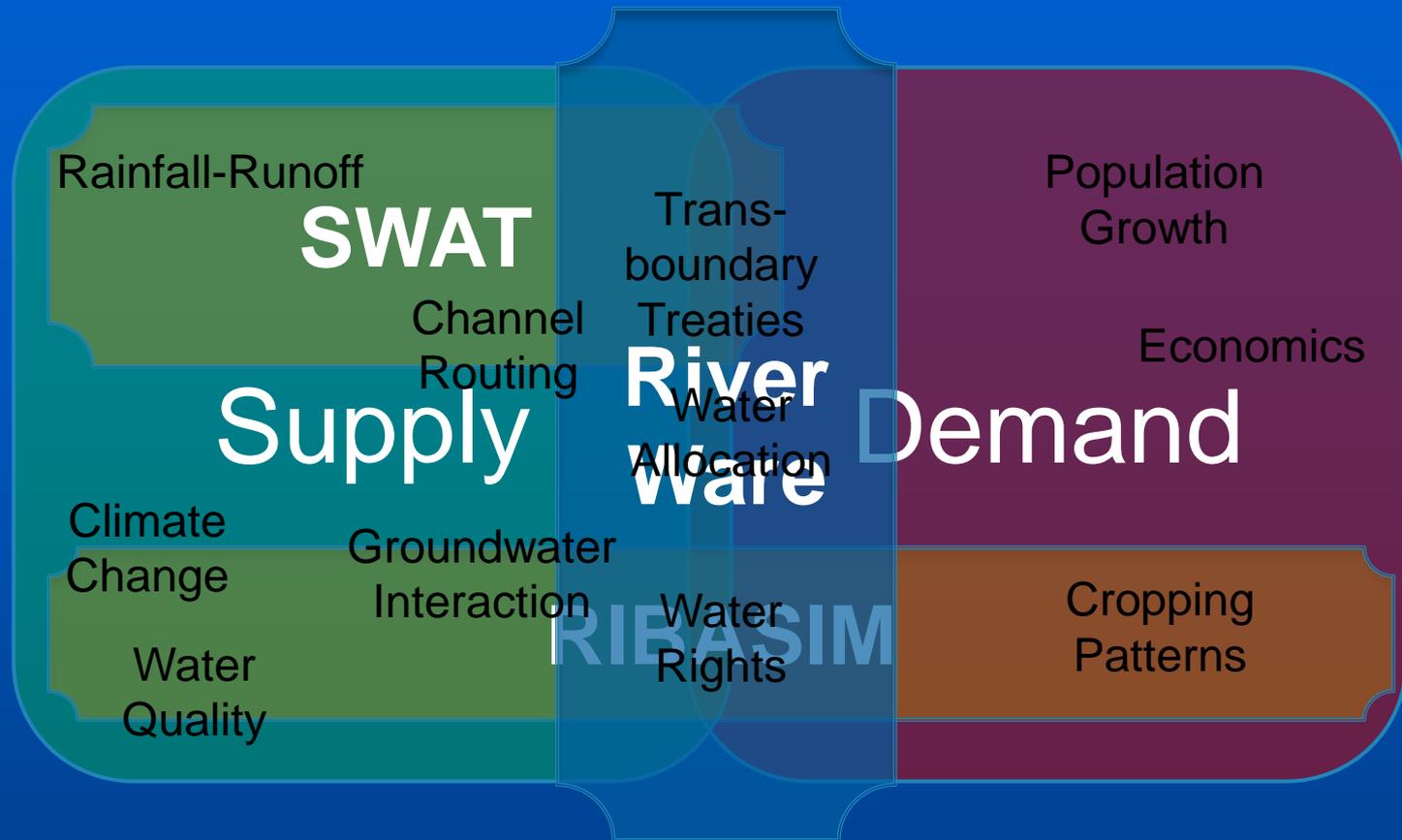
HEC ResSim

SWAT

Nile DST

RAPSO

# STRENGTHS OF ENPM MODELS

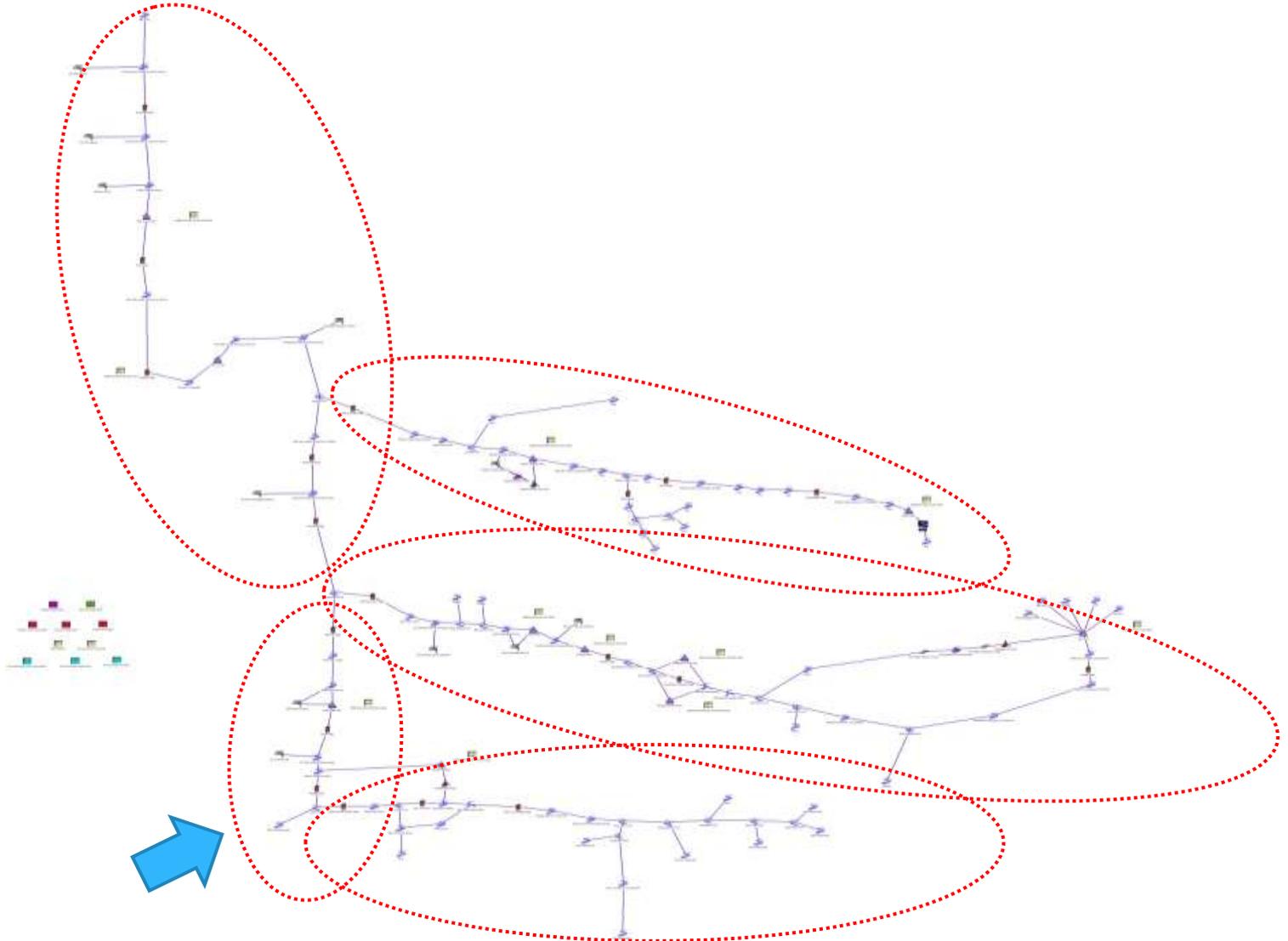


- **Complex Supply-Demand Interactions**
- **Reservoir Operations**
- **Multiple Management Scenarios**
- **Policy Interactions**

# Model Design

- ⦿ Monthly time step planning model
- ⦿ 1956-1990 Hydrology (for now)
- ⦿ Repeating demand patterns (for now)
- ⦿ Simulate reservoir operations
- ⦿ Calibrate channel losses, lag times, evaporation rates

# Model Workspace

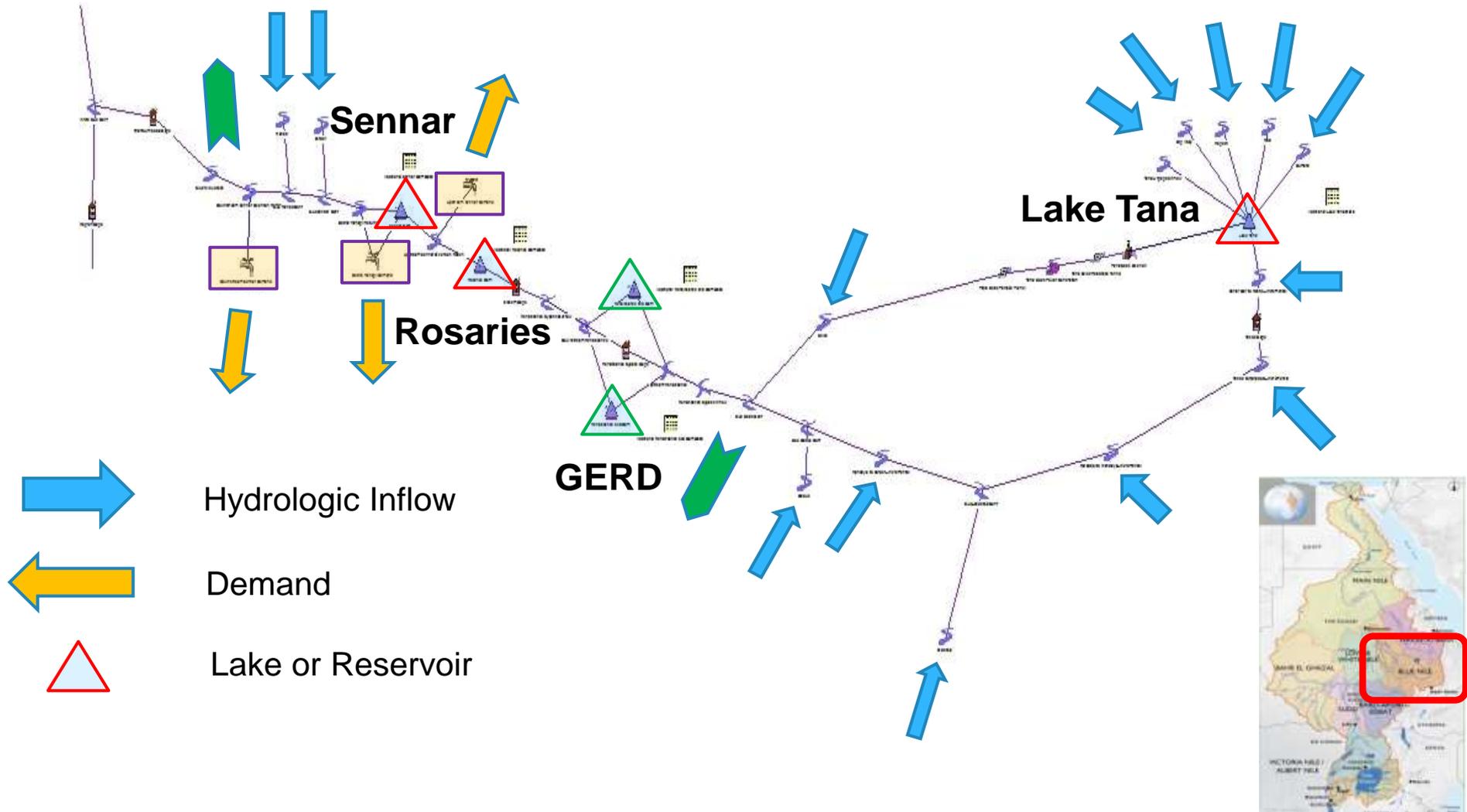


# Data Inputs

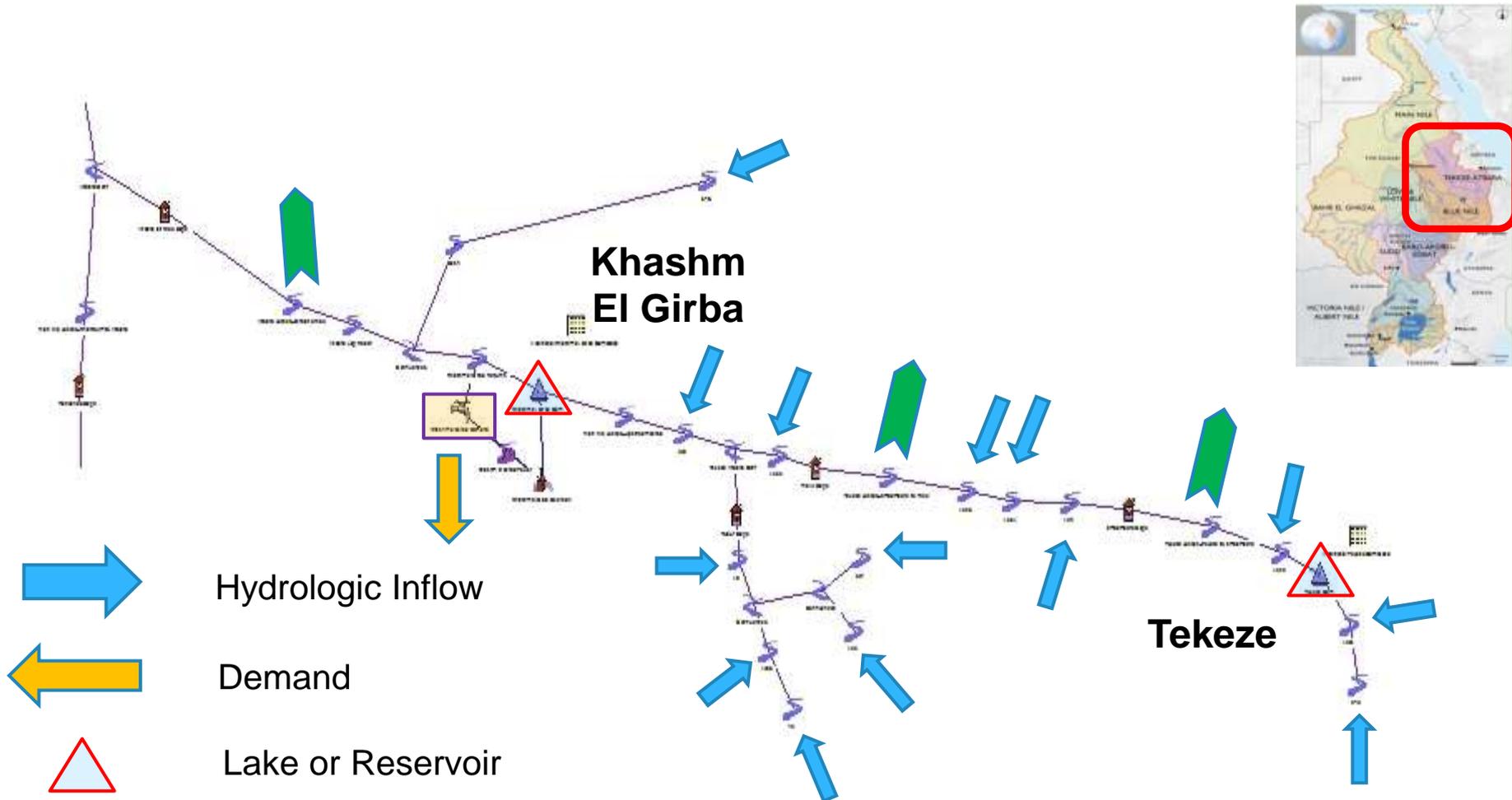
- ⦿ Hydrologic Flows
  - Nile Encyclopedia
  - NBI DSS Work Product II
- ⦿ Consumptive Uses
  - NBI DSS Work Product II
- ⦿ Reservoir Operations
  - ENTRO Products: Irrigation Tool Kit, Power Tool Kit
  - Unpublished Reports
  - Published Reports
  - Conversations with NBI/ENTRO Staff
  - Conversations with University Staff, Water Ministry Personnel, Dam Operators

**Data Challenges – Poor Data Sharing, Distrust of Data, Public vs. Internal Sources**

# Blue Nile Input Locations

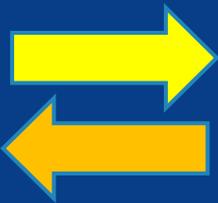


# Tekeze-Setit-Atbara Inflow Locations



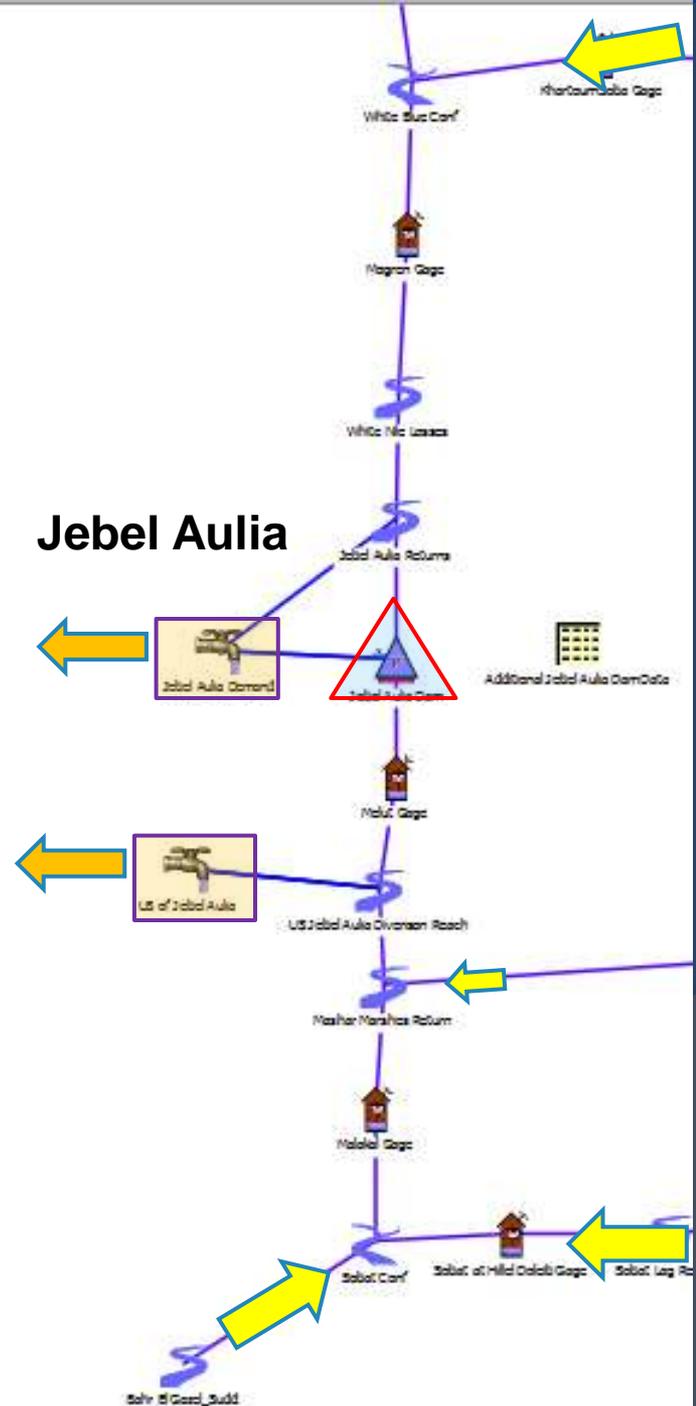


# White Nile Input Locations

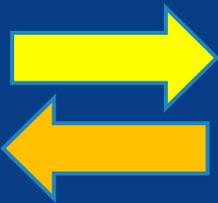


Calculated Inflow Input

Demand Input

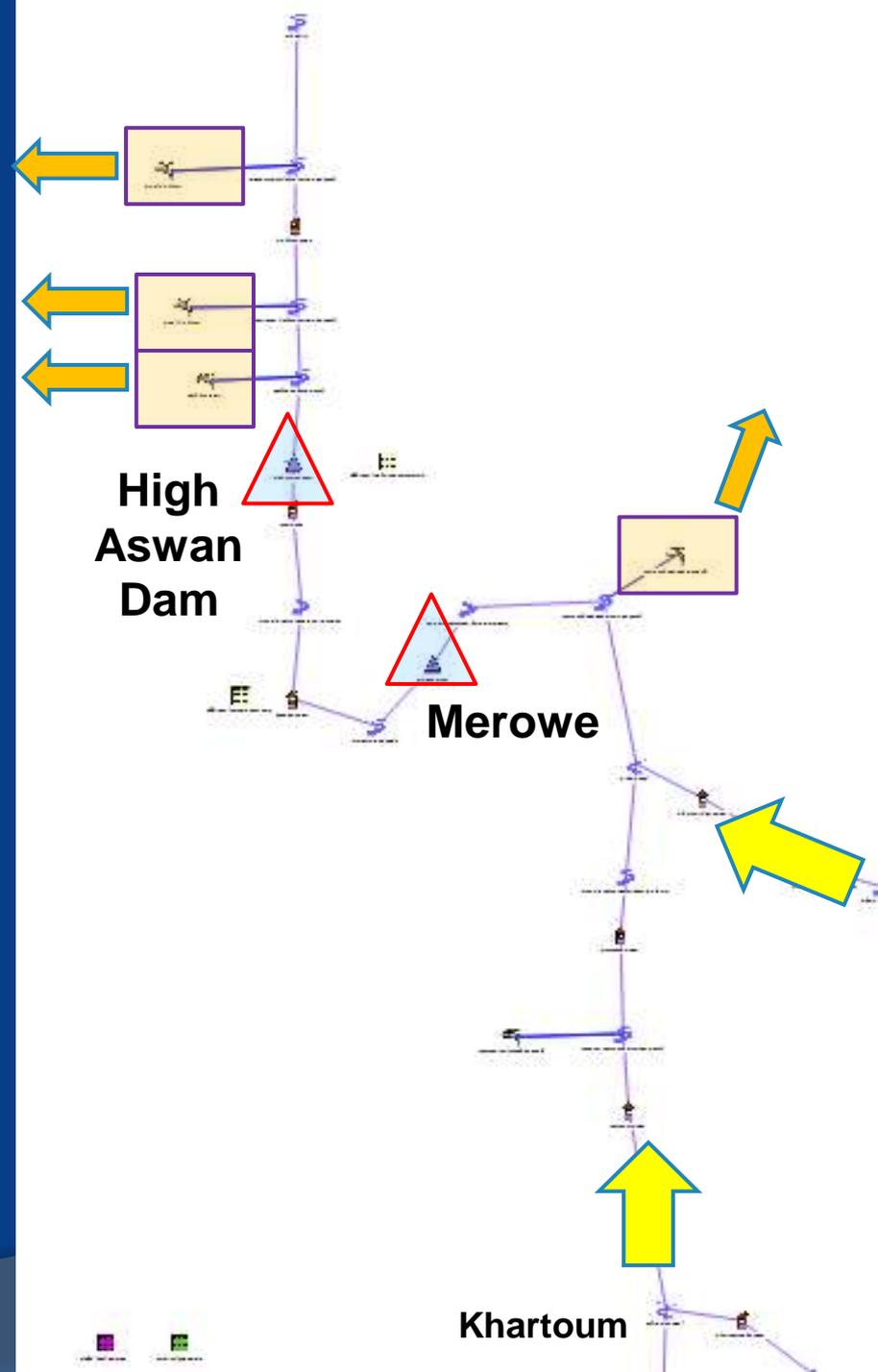


# Main Nile Input Locations



Calculated Inflow Input

Demand Input



# Rosaries Power Plant Characteristics

Power Plant Principal Characteristics

	Roseires		Heightened + Dinder	
	Existing		7x40 + 3x45	415.00
Maximum capacity (MW)	7 x 40	280.00	7x40 + 3x45	415.00
Maximum discharge (m3/s)	1031.65		1538.00	
Level / Energy coefficient : -	Level (m)	Coefficient (m3/s/MW)	Level (m)	Coefficient (m3/s/MW)
	467.00	5.92	-	-
	469.00	5.45	-	-
	471.00	5.05	471.00	5.22
	473.00	4.70	473.00	4.83
	475.00	4.39	475.00	4.50
	477.00	4.12	477.00	4.18
	479.00	3.89	479.00	3.89
	481.00	3.68	481.00	3.65
			483.00	3.44
			485.00	3.28
			487.00	3.12
			489.00	2.96
			490.00	2.89
Sources	NEC		M&M 1997	

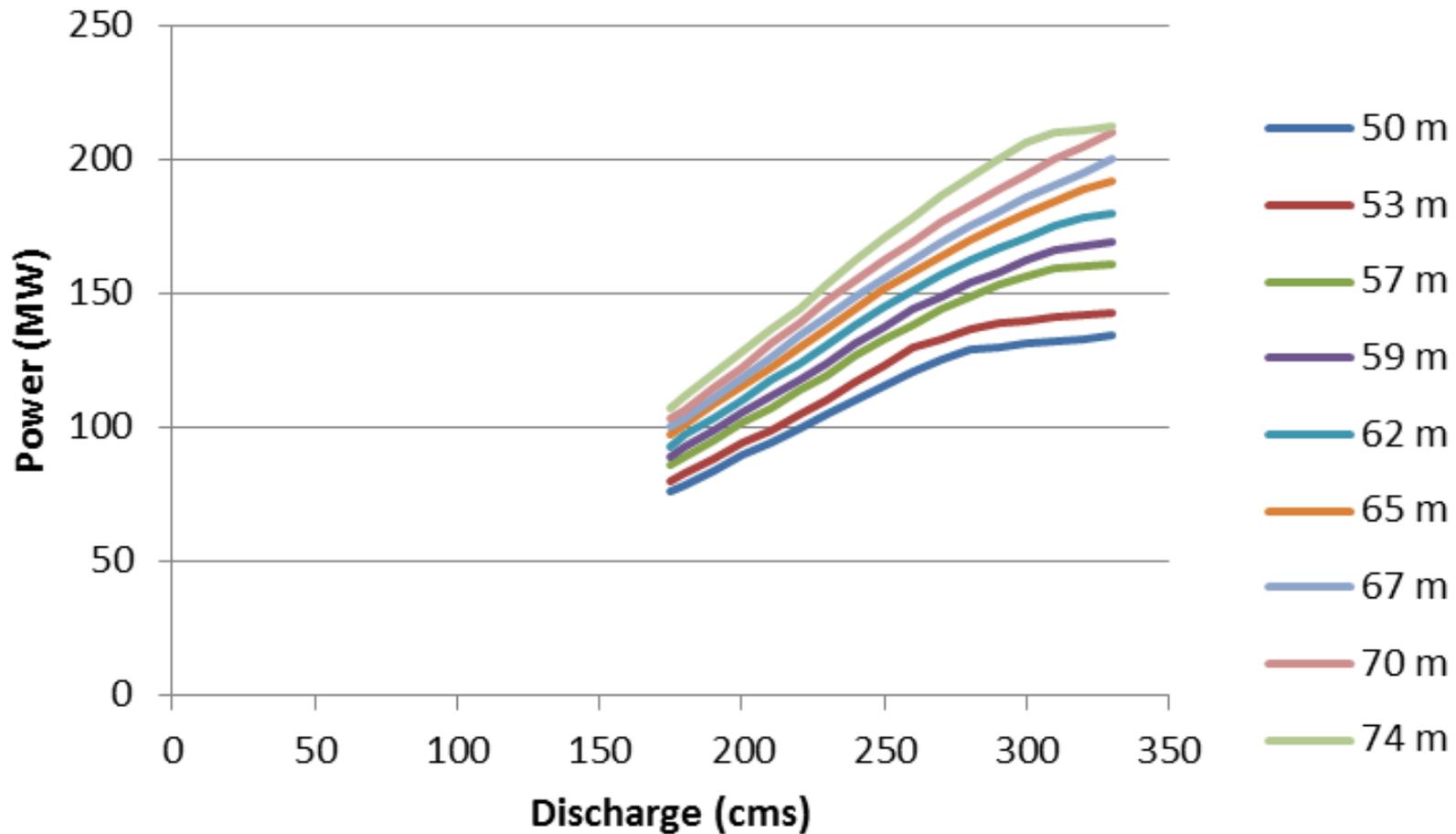
Elevation	Max Head	Total Max Capacity		Capacity Per Gate CMS
		MCM	CMS	
467.00	25.00	440.35	5096.67	728.10
468.00	26.00	449.07	5197.61	742.52
469.00	27.00	457.63	5296.62	756.66
470.00	28.00	466.03	5393.81	770.54
471.00	29.00	474.27	5489.28	784.18
472.00	30.00	482.38	5583.12	797.59
473.00	31.00	490.36	5675.41	810.77
474.00	32.00	498.20	5766.23	823.75
475.00	33.00	505.93	5855.63	836.52
476.00	34.00	513.53	5943.69	849.10
477.00	35.00	521.03	6030.46	861.49
478.00	36.00	528.42	6116.01	873.72
479.00	37.00	535.71	6200.37	885.77
480.00	38.00	542.90	6283.60	897.66
481.00	39.00	550.00	6365.74	909.39

# Rosaries: Selecting a Power Calculation Method

## 21.1.1.3 plantPowerCalc

The plantPowerCalc method calculates the Power and Energy generated based on the whole plant characteristics. **If the Power Coefficient is specified**, the Power is calculated directly, unless the BEST EFFICIENCY or MAX CAPACITY flag is set on Energy. If its not input, the **Power Coefficient is found from the interpolation** of the Best or Max Turbine Q and Power Coefficient tables using the current Operating Head. If the Turbine Release is less than the Best Turbine Q, the Best Power Coefficient Table is used. If the Turbine Release is greater than the Max Turbine Q, then the Max Power Coefficient Table is used. If the Turbine Release is between the two, an intermediate Power Coefficient Value is found by interpolation.

# High Aswan Turbine Characteristics



# Rule Execution Order

RBS Ruleset Editor - "East Nile Baseline Model\_Working Versio..."

File Edit Set View

baseline Model\East Nile Baseline Model\_Working Version\_1.0.rls RPL Set Loaded

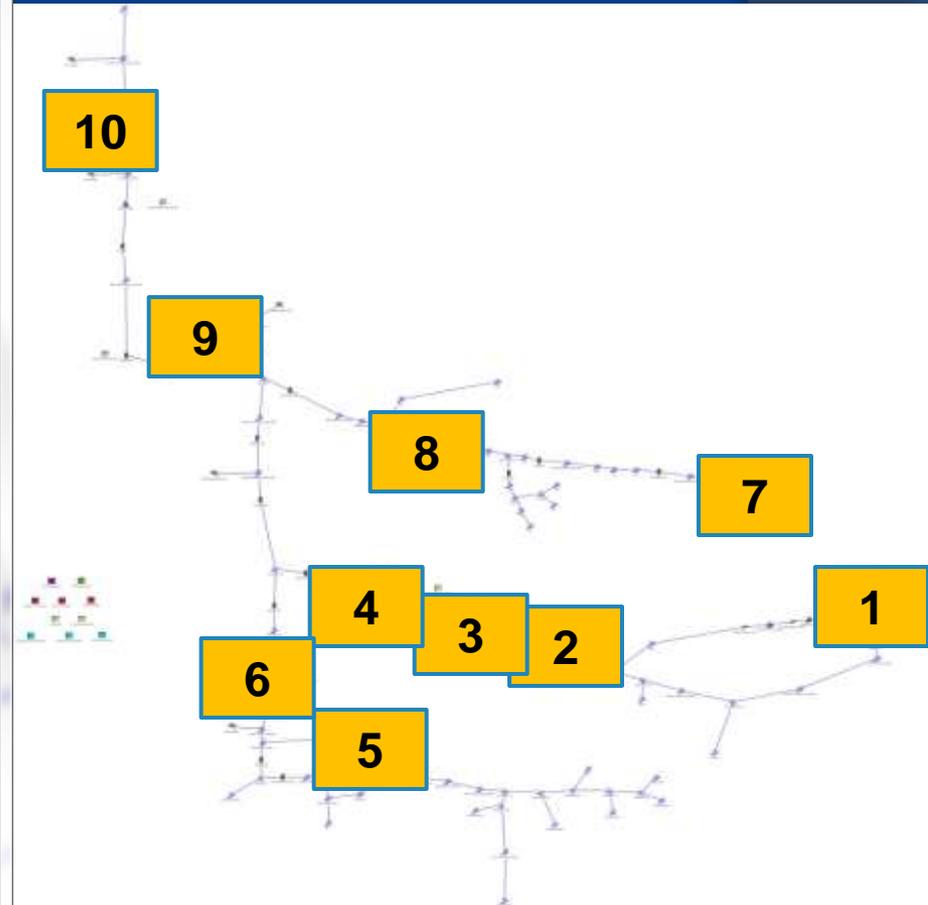
Policy & Utility Groups Report Groups

Name	Priority	On	Type
▶ <b>P</b> High Aswan Dam Rules	1-6	✓	Policy Group
▶ <b>P</b> Merowe Dam Rules	7-8	✓	Policy Group
▶ <b>P</b> Khashm El Girba Rules	9-11	✓	Policy Group
▶ <b>P</b> Tekeze Dam Rules Group	12-14	✓	Policy Group
▶ <b>P</b> Jebel Aulia Dam Rules	15-17	✓	Policy Group
▶ <b>P</b> Machar Marshes Rules	18-21	✓	Policy Group
▶ <b>P</b> Sennar Dam Rules	22-25	✓	Policy Group
▶ <b>P</b> Roseries Dam Rules	26-28	✓	Policy Group
▶ <b>P</b> Renaissance Dam Rules	29-35	✓	Policy Group
▶ <b>P</b> Lake Tana Rules	36-39	✓	Policy Group
▶ <b>U</b> Reservoir Functions		✓	Utility Group

**↑**

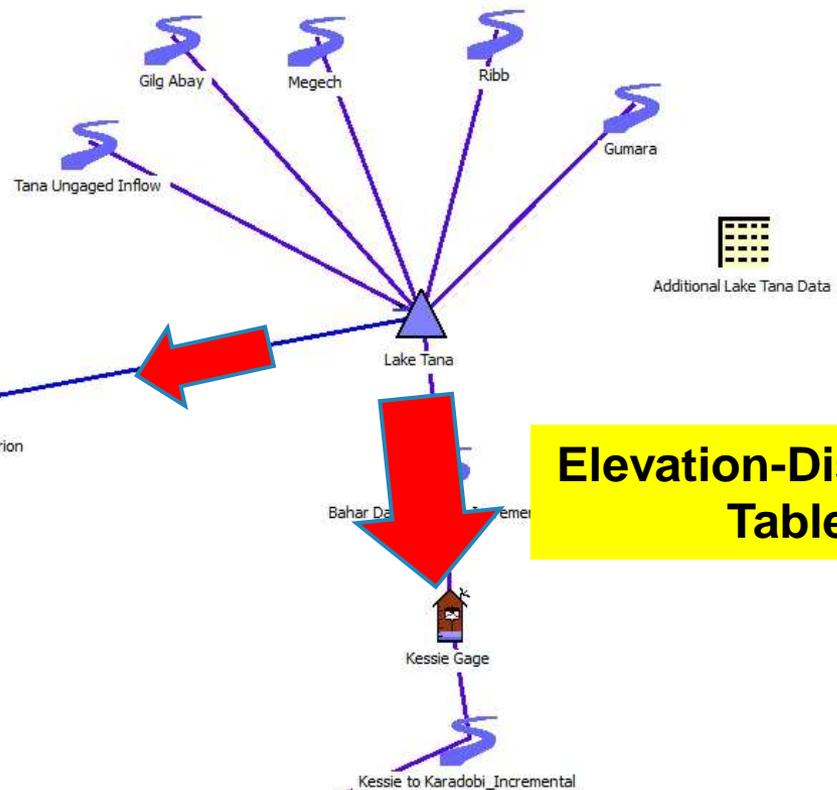
**BOTTOM TO TOP!**

Show:  Set Description  Selected Description  Adv. Properties



# Lake Tana Operation

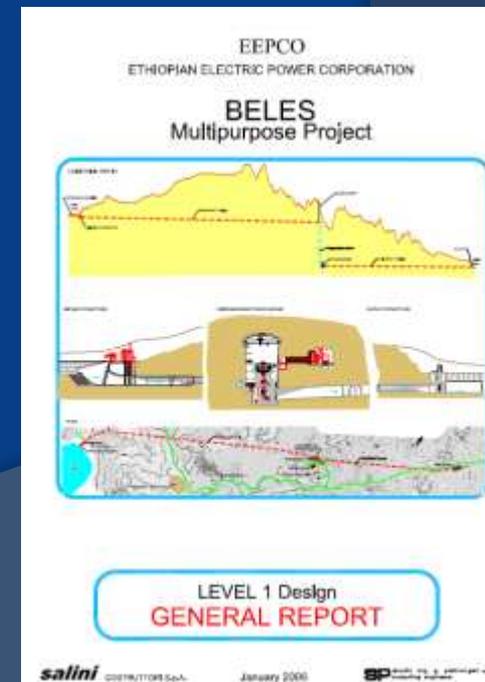
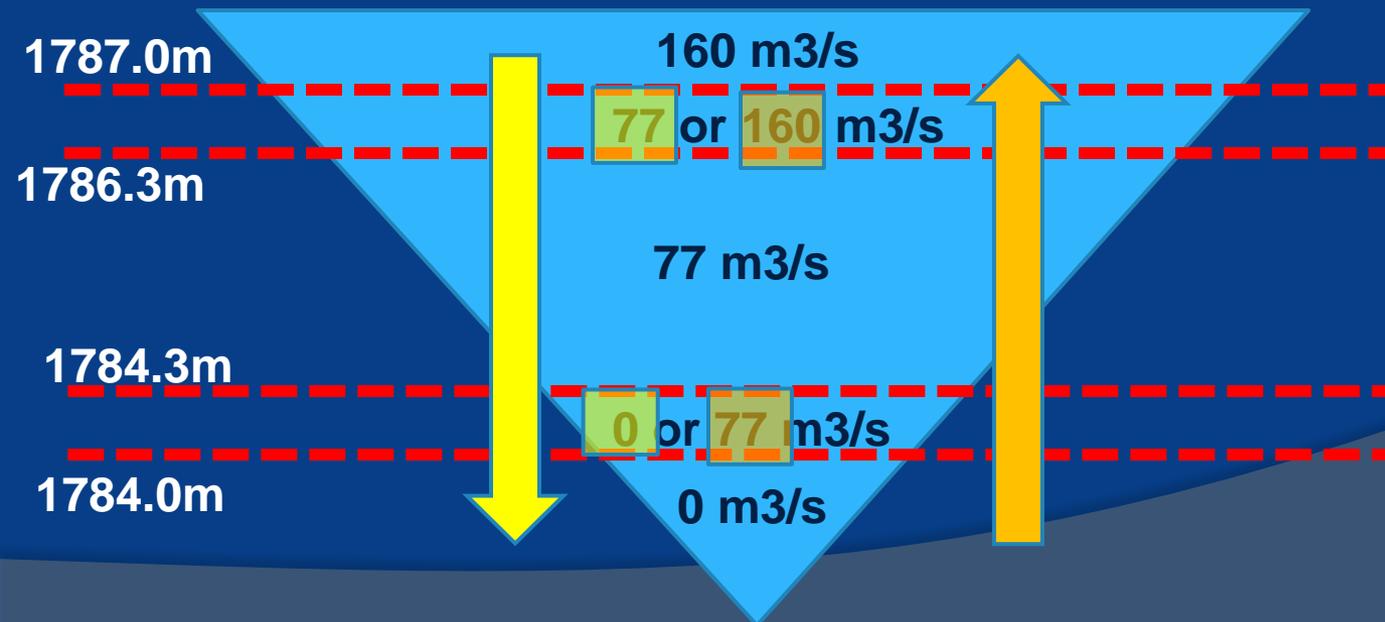
**Complex Elevation-Based Diversion**



**Elevation-Discharge Table**

# Operation of Tana Beles

- Q\_turb = 77 m<sup>3</sup>/s, IF 1784.3 ≤ LWL ≤ 1786.3
- Q\_turb = 0 m<sup>3</sup>/s, IF LWL ≤ 1784 OR (LWL < 1784.3 AND d(LWL)/dt < 0)
- Q\_turb = 77 m<sup>3</sup>/s, IF 1784 < LWL < 1784.3 AND d(LWL)/dt > 0
- Q\_turb = 77 m<sup>3</sup>/s, IF 1786.3 ≤ LWL ≤ 1787 AND d(LWL)/dt < 0
- Q\_turb = 160 m<sup>3</sup>/s IF LWL ≥ 1787 OR (LWL ≥ 1786.3 AND d(LWL)/dt > 0)



# Prioritized Reservoir Operations

	Target Elevations	Elevation-Discharge	Target Discharge	Meet Power Objectives	Meet Direct Diversions	Meet Downstream Diversions	Meet Environmental Requirements
Lake Tana		1					
Roseries Dam	3					1	2
Sennar Dam	4				1	2	3
Tekeze Dam				2			1
Khashm El Girba Dam	3				1		2
Jebel Aulia	2				1		
Merowe Dam				1			
High Aswan Dam			1				
Karadobi Dam				2			1
Beko Abo High Dam				2			1
Beko Abo Low Dam				2			1
Mendaya Upper Dam				2			1
Mendaya Dam				2			1
Renaissance 640 Dam				2			1
Renaissance 620 Dam				2			1

\* Jebel Aulia Target Elevation is dynamically based on Blue Nile Peak Flows

# Rosaries Operations

RBS Ruleset Editor - "East Nile Baseline Model\_Working Version\_1.0\_KGWSynchronize1\_Heighthen Rosaries2.rls"

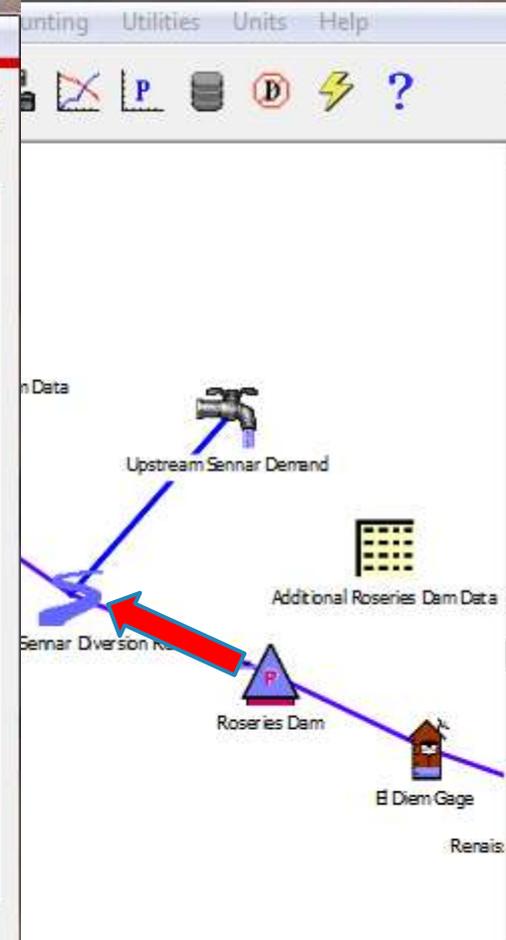
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Policy & Utility Groups Report Groups

Name	Priority	On	Type
▶ P High Aswan Dam Rules	1-6	✔	Policy Group
▶ P Merowe Dam Rules	7-8	✔	Policy Group
▶ P Khashm El Girba Rules	9-11	✔	Policy Group
▶ P Tekeze Dam Rules Group	12-14	✔	Policy Group
▶ P Jebel Aulia Dam Rules	15-17	✔	Policy Group
▶ P Machar Marshes Rules	18-21	✔	Policy Group
▶ P Sennar Dam Rules	22-25	✔	Policy Group
▶ P Roseries Dam Rules		✔	Policy Group
#4 R Augment Roseries Dam Outflow to Meet Environmental Requirements	26	✔	Rule
#3 R Augment Roseries Dam Outflow to Meet Downstream Demands	27	✔	Rule
#2 R Set September Roseries Dam Outflow To Immediately Fill Reservoir	28	✔	Rule
#1 R Set Roseries Dam Outflow By Target Elevation	29	✔	Rule
▶ P Renaissance Dam Rules	30-36	✔	Policy Group
▶ P Lake Tana Rules	37-40	✔	Policy Group
▶ U Reservoir Functions		✔	Utility Group

Show:  Set Description  Selected Description  Adv. Properties



# Three Phase Approach

Phase 1: Calibration Model

Phase 2: Baseline Model

Phase 3: Scenario Model

# Agenda Topics

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# Proposed Infrastructure

## Blue Nile

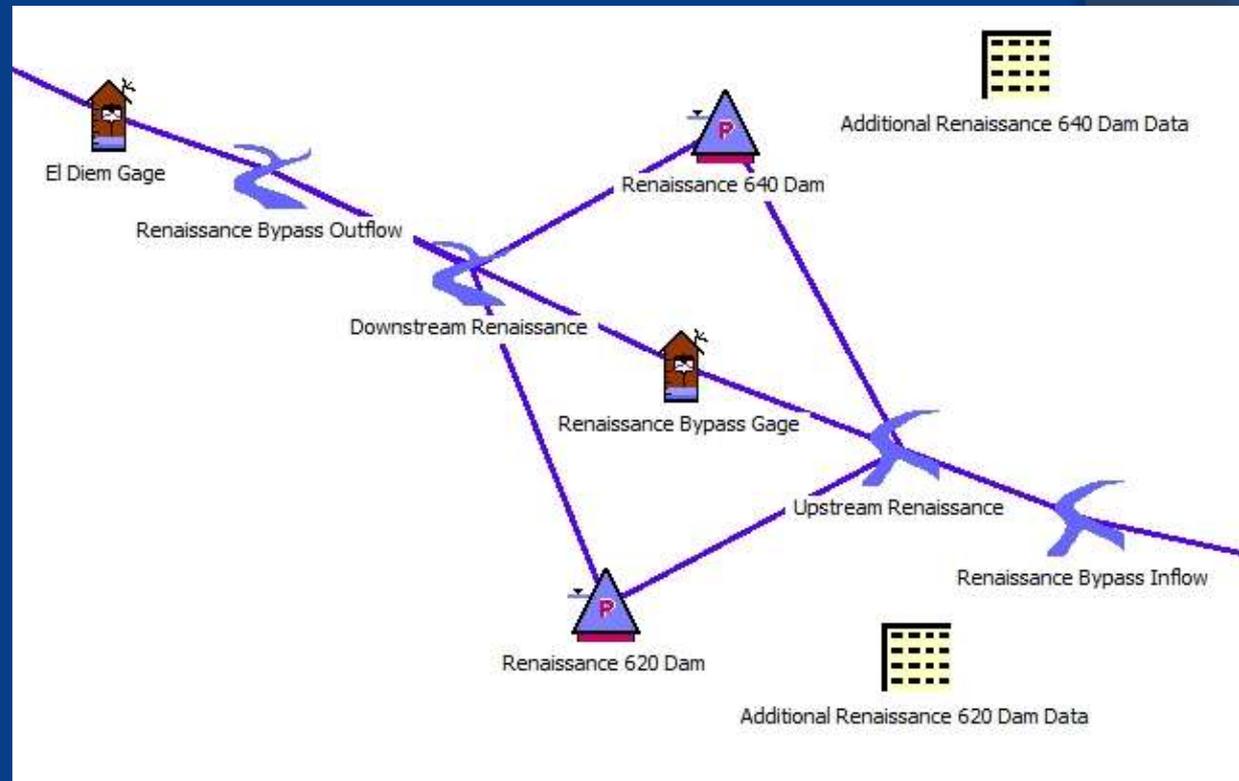
- Karadobi Dam
- Beko Abo High Dam
- Beko Abo Low Dam
- Mendaya Upper Dam
- Mendaya Dam
- Renaissance 640 Dam
- Renaissance 620 Dam
- Didessa Dam

## Baro-Akobo-Sobat

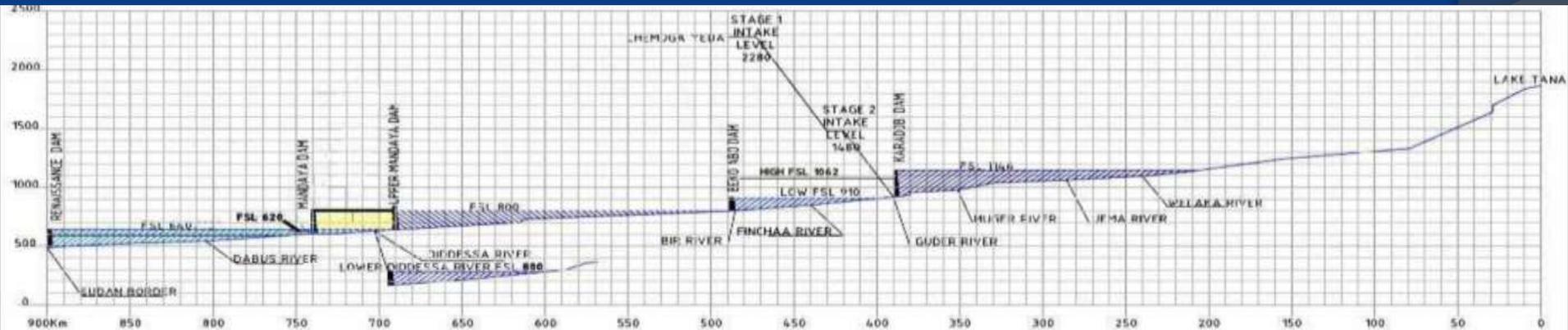
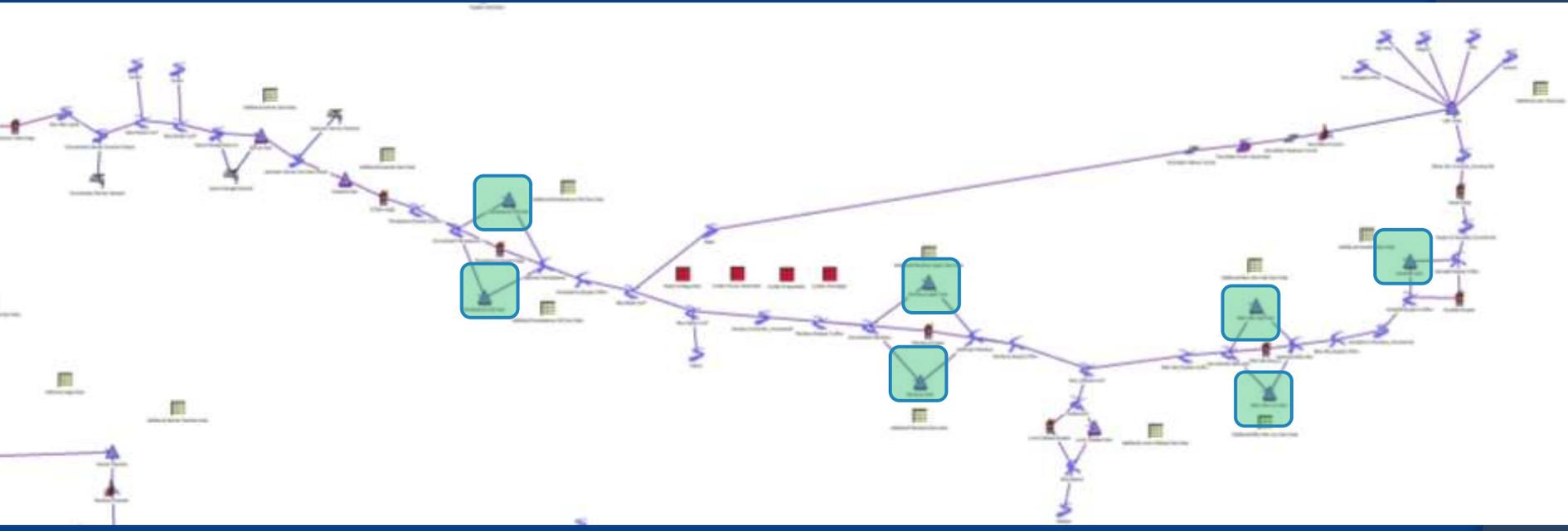
- Baro 1 Dam
- Baro 2 Dam

## Main Nile

- Sherieg
- Kajbar



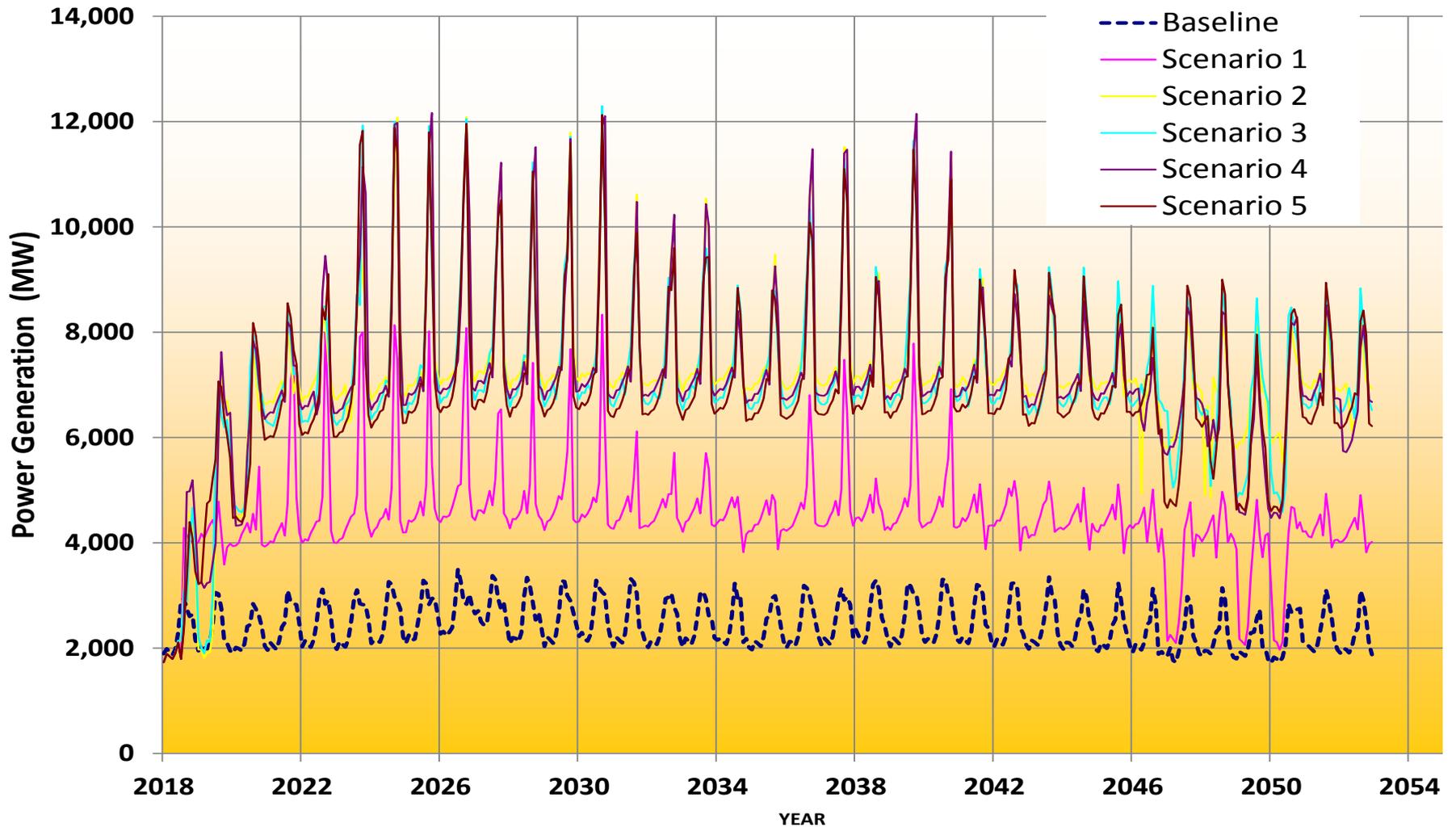
# Proposed Infrastructure on the Blue Nile



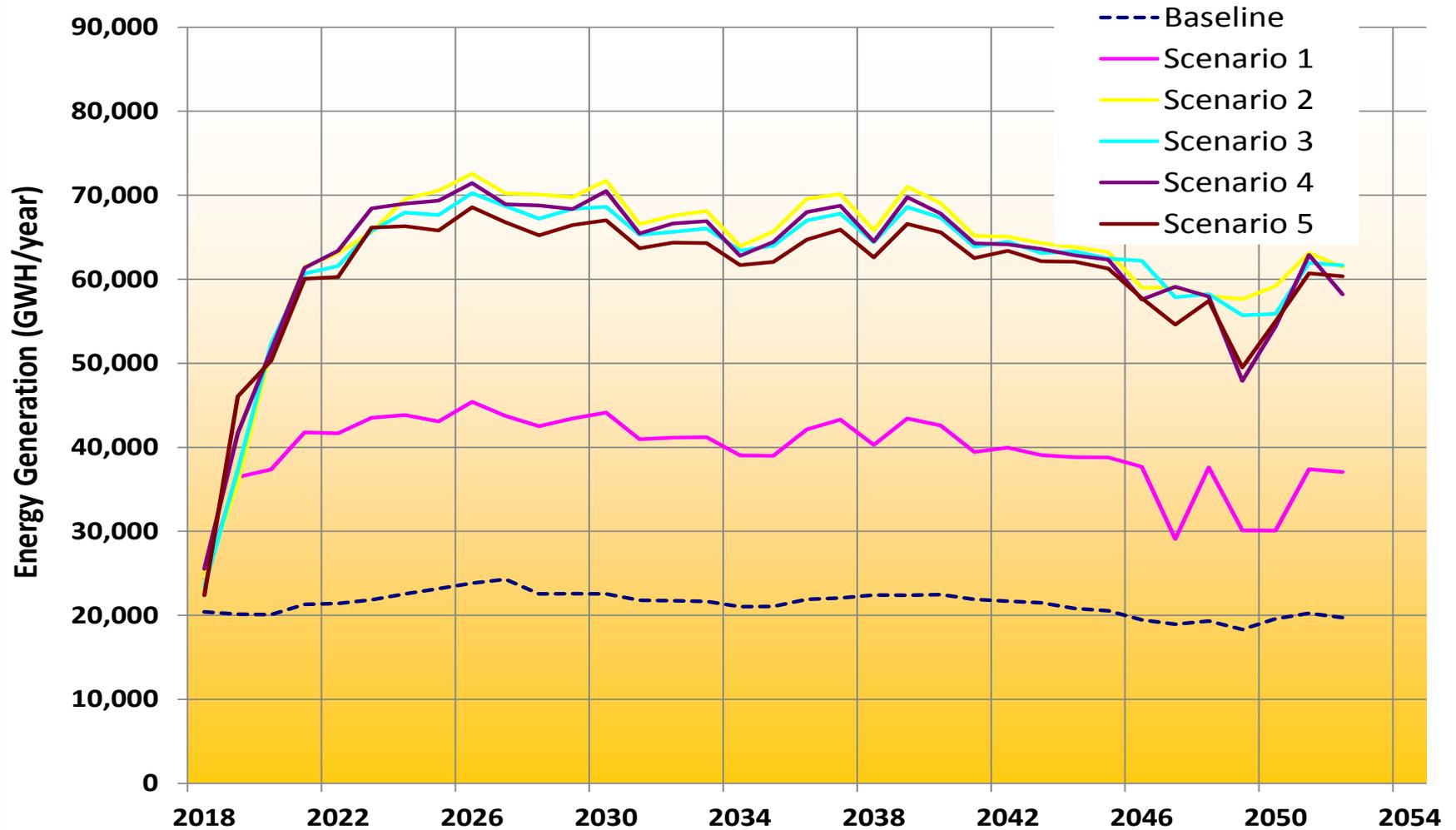
# Scenario Analysis

- ⦿ Baseline
- ⦿ Scenario 1: Renaissance 640
- ⦿ Scenario 2: Karadobi + Beko Abo Low + Mendaya + Renaissance 620
- ⦿ Scenario 3: Karadobi + Beko Abo Low + Mendaya Upper + Renaissance 640
- ⦿ Scenario 4: Beko Abo High + Mendaya + Renaissance 620
- ⦿ Scenario 5: Beko Abo High + Mendaya Upper + Renaissance 640
  
- ⦿ Proposed Reservoirs Operated:
  1. Meet Hydropower Demands
  2. Allow Minimum Environmental Releases

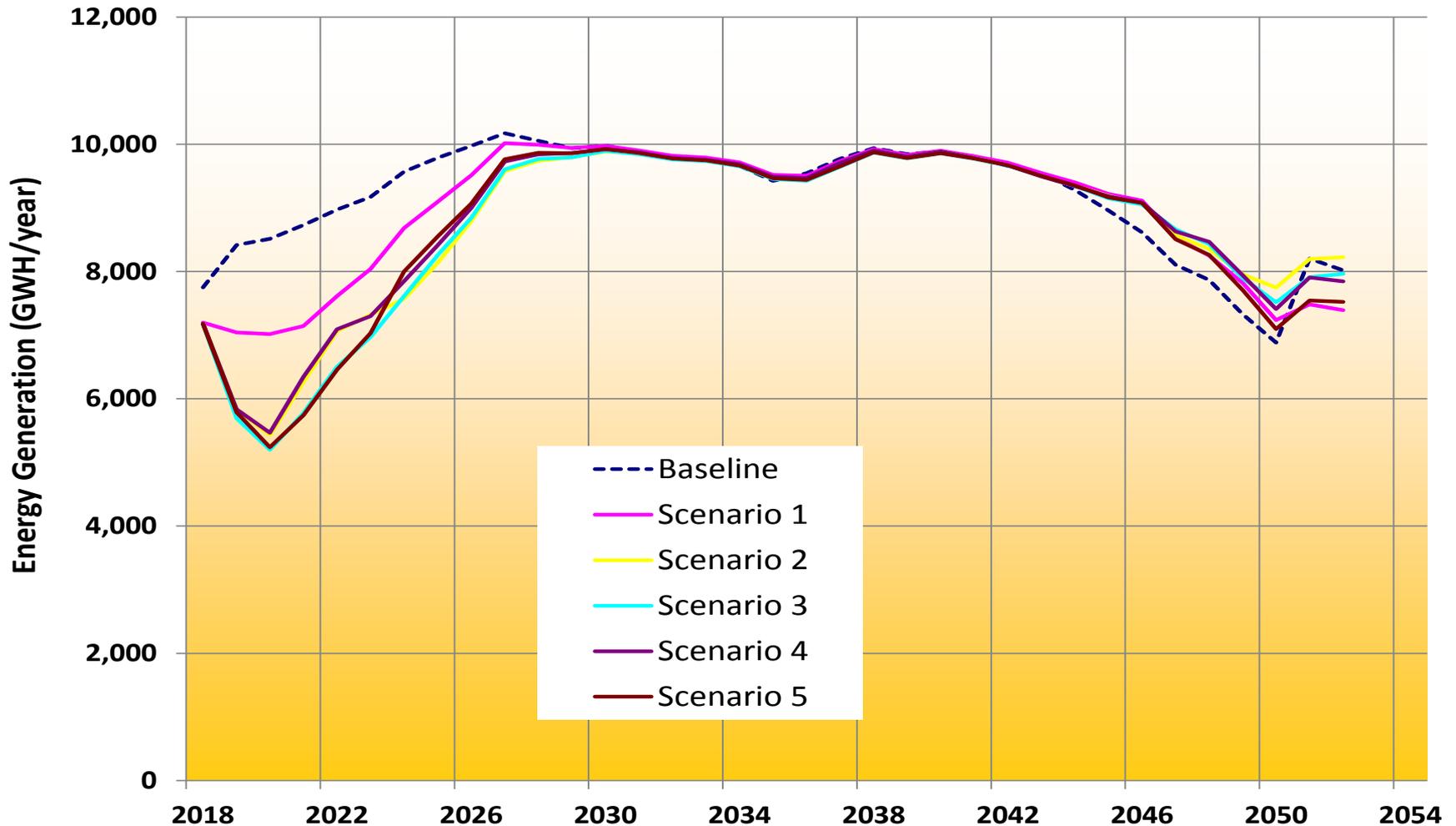
# Total System Power Generation



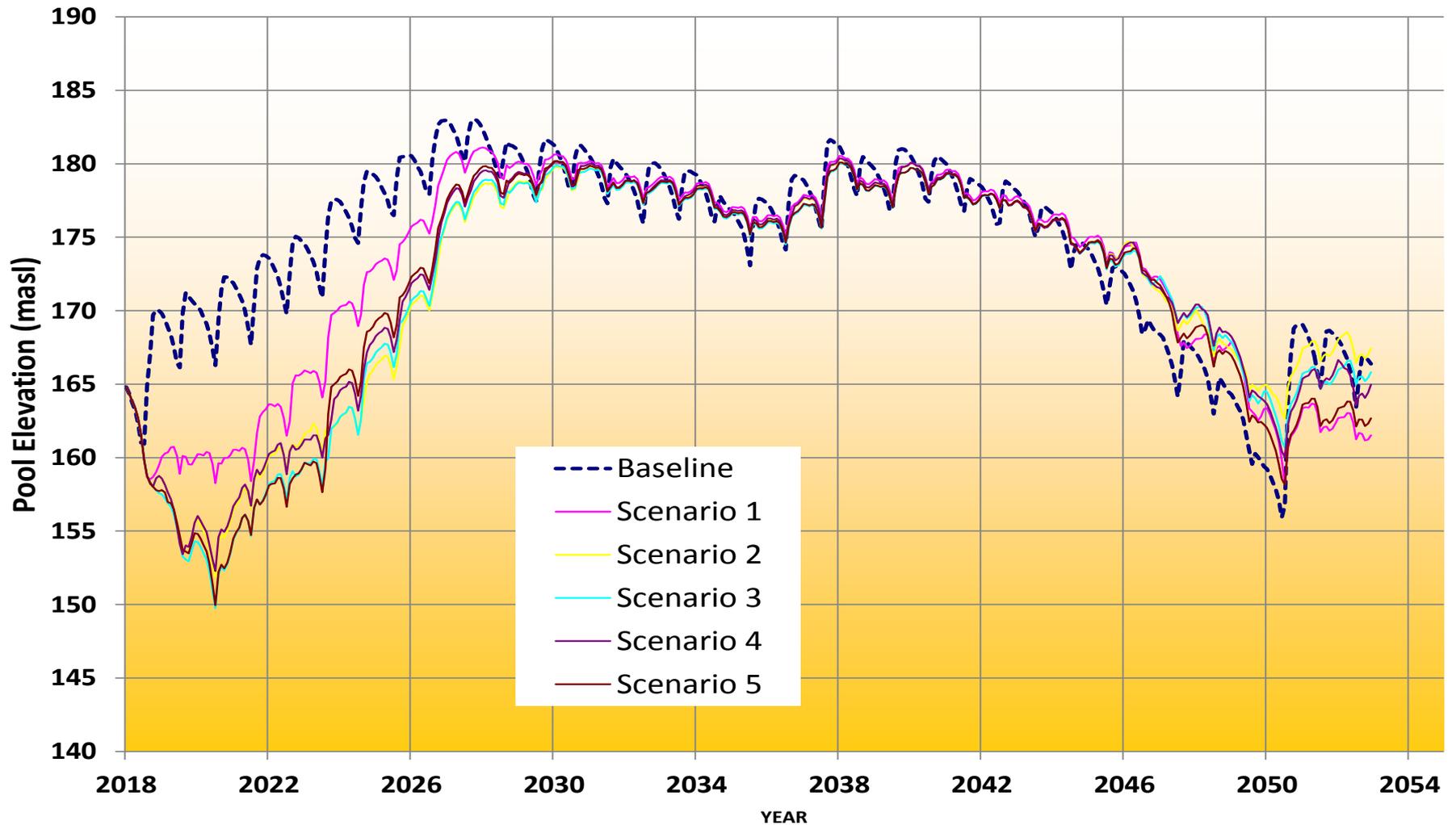
# Total System Annual Energy Output



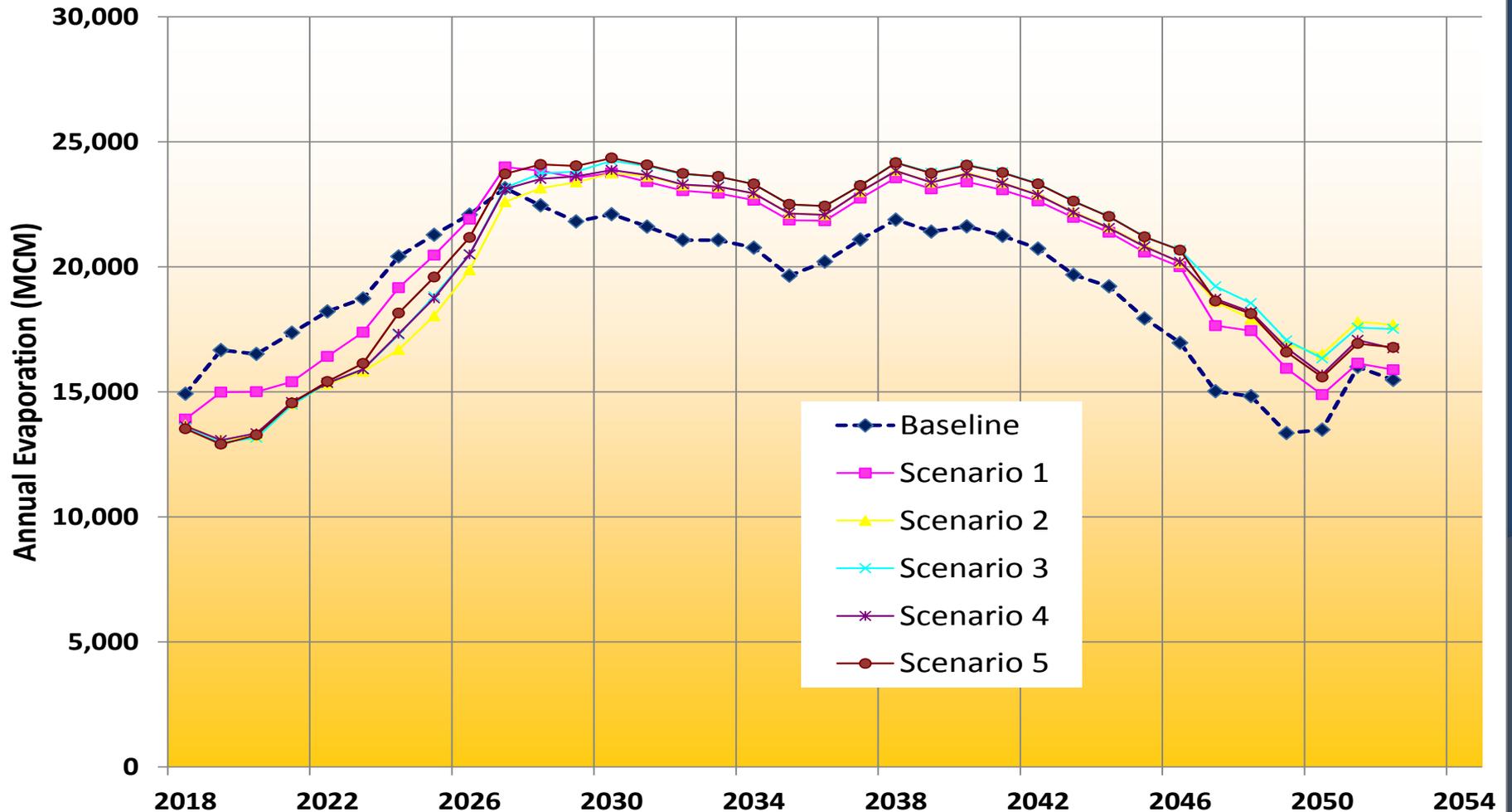
# Total Egyptian Annual Energy Output



# High Aswan Pool Elevation



# Total East Nile Reservoir Evaporation



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# POTENTIAL APPLICATIONS

- ◉ Renaissance Dam Reservoir Filling
- ◉ Coordination of Sudanese Reservoirs
- ◉ New Ethiopian Reservoir Operation Paradigms
  - Maximize Energy -> Ethiopia/System Hydropower
  - Minimum Impact -> Run-of-River
  - Protect Agriculture and Enviro - > Design Floods
  - Coordination -> Meet Downstream Demands
- **How Can Reservoir Operations be Coordinated Across Borders to Eliminate or Minimize Harm to Sudan and Egypt?**

**BENEFIT SHARING**



# BENEFIT SHARING

- ⦿ Don't just Share the Water
- ⦿ Share the Benefits that a River Provides
  - Economic Benefits
  - Environmental Benefits
  - Benefits of Reduced Tensions
  - Benefits of Regional Integration

(Sadoff and Grey, 2002)

# MOVING FORWARD

## 1. TRAINING — Cairo, Khartoum, Addis Ababa

- Training with the RiverWare Software – 3 Days
- Training with the Eastern Nile Model – 2 Days



## 2. REFINE MODEL

- Country/Stakeholder Driven
- Refine Projected Demands
- Verify Evaporation Rates
- Current Reservoir Operations
- Multiple Hydrologic Traces – **Climate Change** Inputs



## 3. EXPAND and EXPLORE

- Working Together To Explore Options
- Create an online Technical Working Group
- Joint Recommendations for Operations





Questions?  
Comments?

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<http://waterbalance.org>