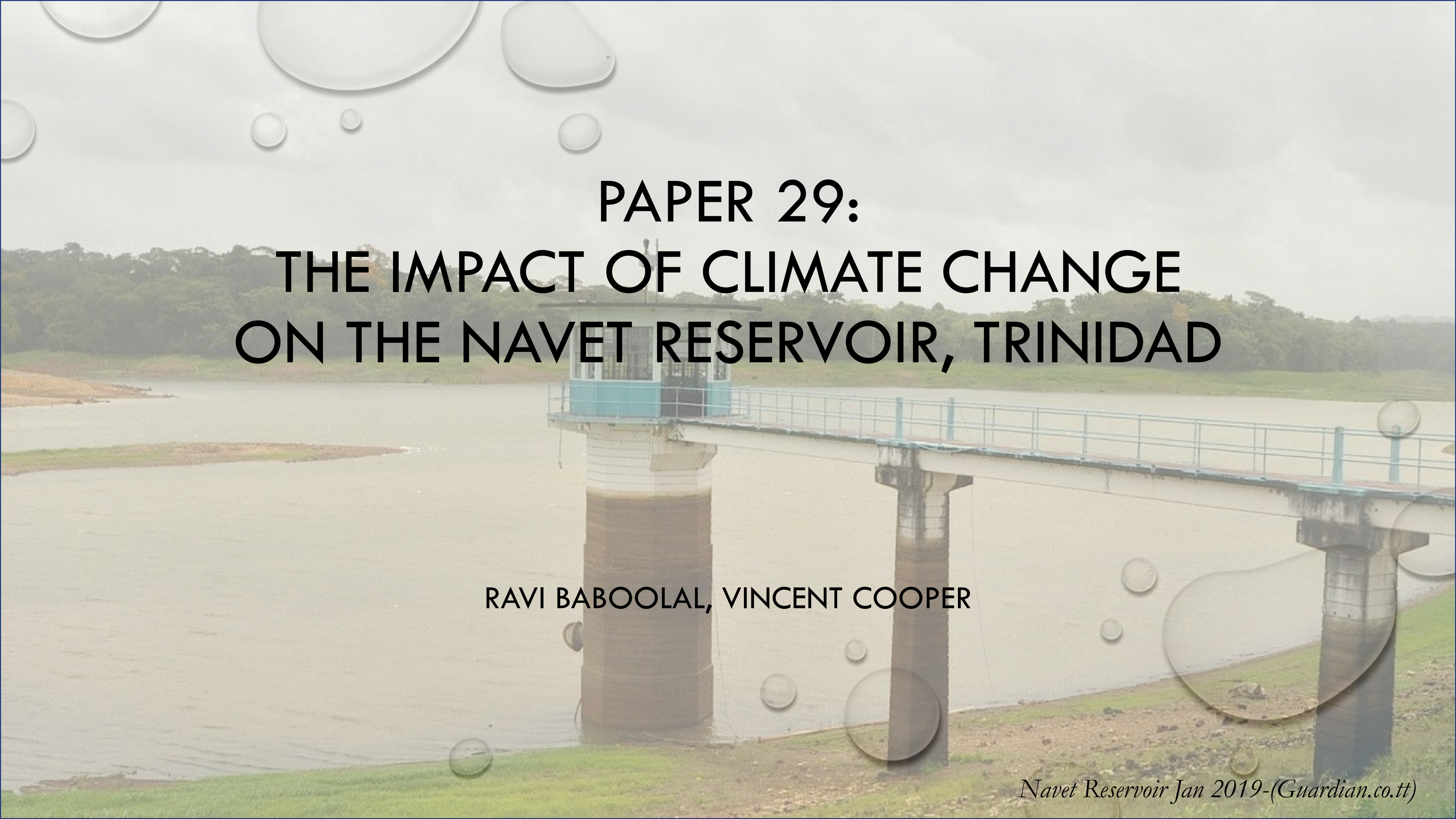
PAPER 29:
THE IMPACT OF CLIMATE CHANGE ON THE NAVET RESERVOIR, TRINIDAD

RAVI BABOOLAL, VINCENT COOPER



Navet Reservoir Jan 2019-(Guardian.co.tt)

OUTLINE

- BACKGROUND
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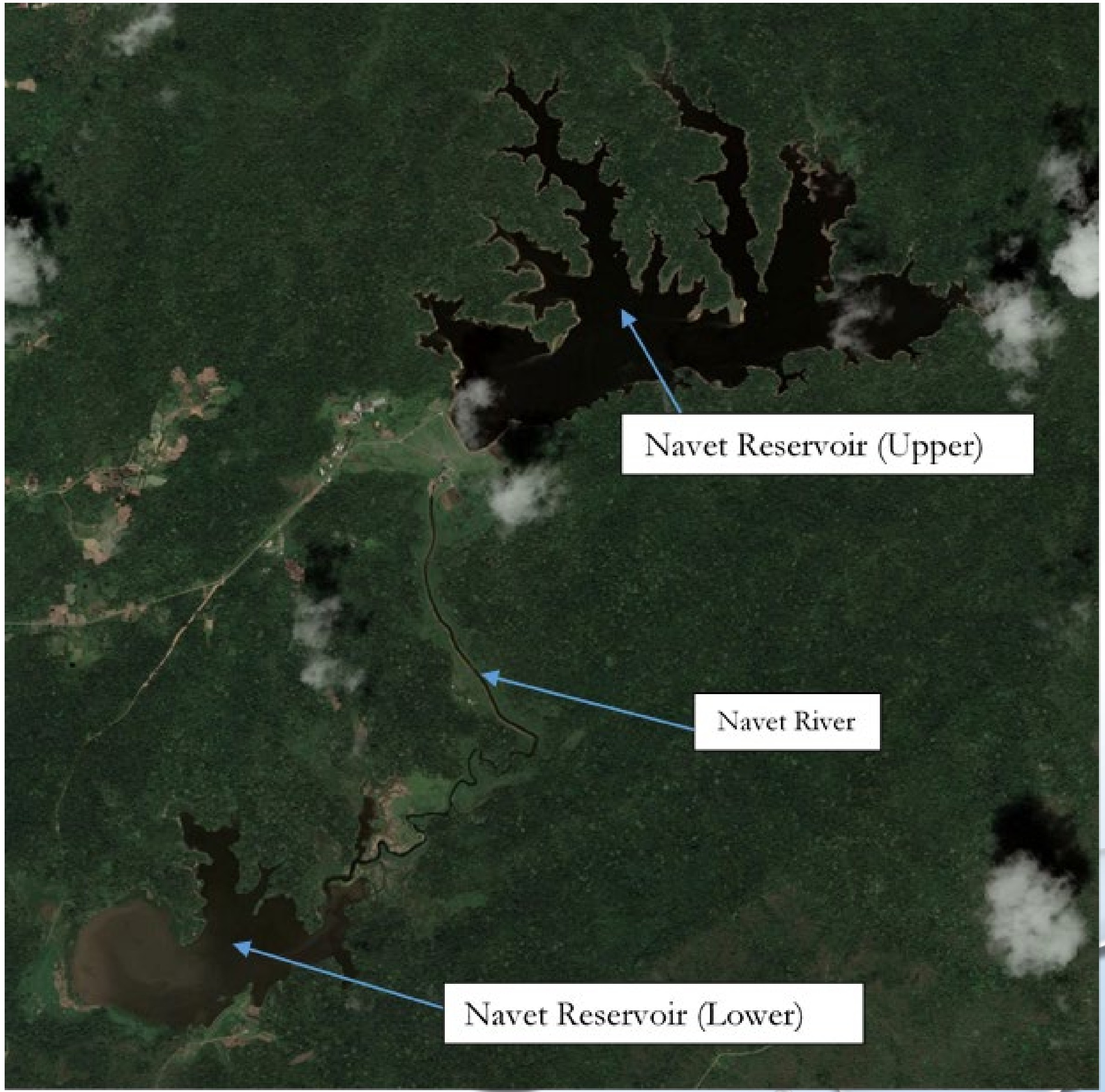
BACKGROUND

- THE NAVET RESERVOIR
  - LOCATED IN CENTRAL TRINIDAD
  - SMALLEST OF 3 SURFACE WATER RESERVOIRS ON THE ISLAND
  - COMPLETED IN 1962 (WITH BOOSTER PUMP STATION AND WATER TREATMENT PLANT)
  - SUPPLIES SOUTH TRINIDAD
  - AVG 86,000 M^3/D

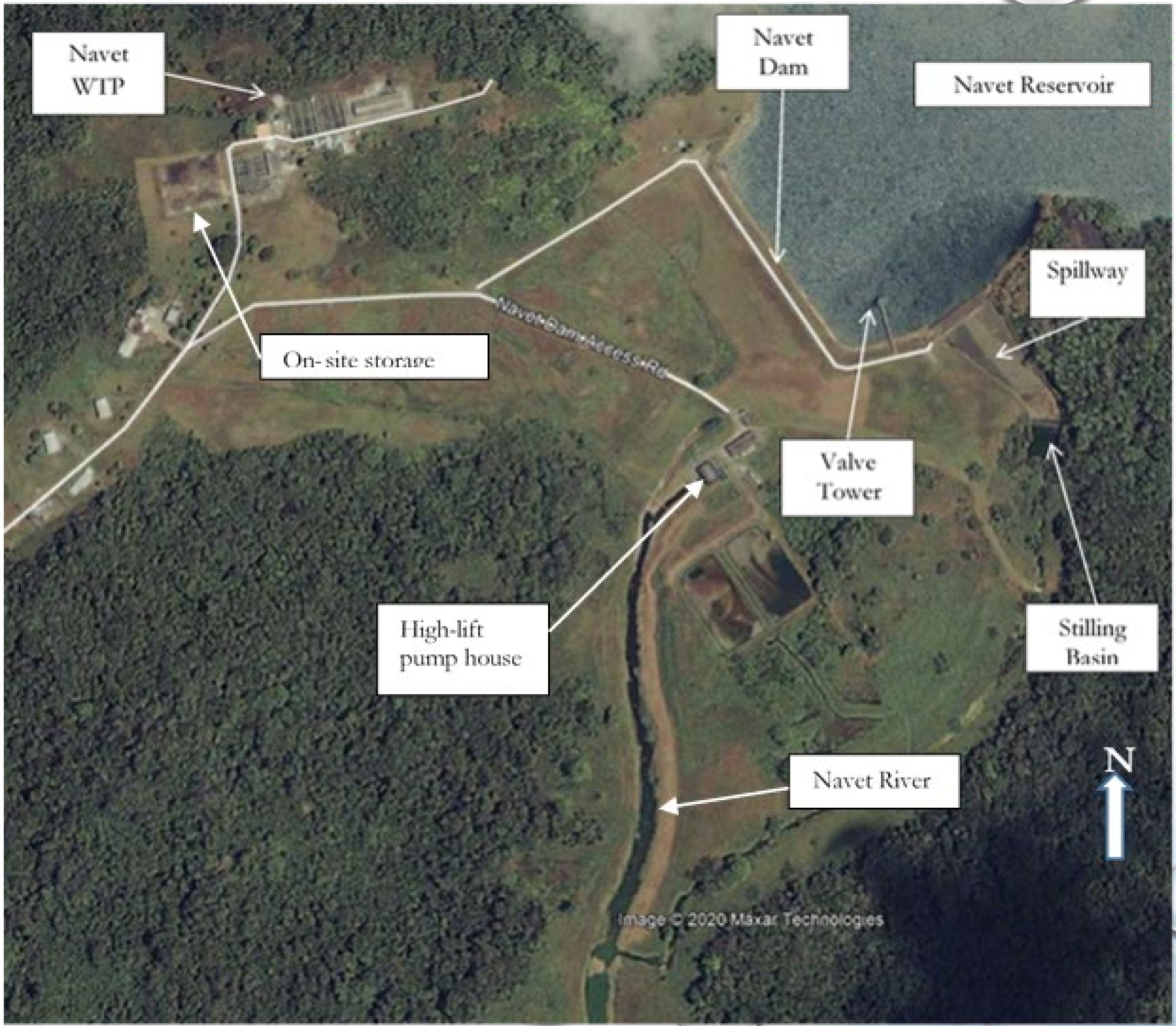
NAVET RESERVOIR SYSTEM (NRS)

- THE NAVET RESERVOIR UPPER (NRU)
  - STORAGE CAPACITY OF APPROXIMATELY 19 MILLION CUBIC METERS
  - ITS CATCHMENT IS APPROXIMATELY 17.57 KM^2.
  - CREATED BY THE DAMMING OF THE NAVET RIVER AND A MAJOR TRIBUTARY.
- THE NAVET RESERVOIR LOWER (NRL)
  - IT IS DOWNSTREAM AND INTERCEPTS THE NAVET RIVER AND A SECOND TRIBUTARY,
  - 4 MILLION CUBIC METERS OF STORAGE CAPACITY TO THE NRS.
  - IT'S CATCHMENT 9.13 KM^2 IN SIZE
  - OVERFLOW FROM THE NRU CONTINUES ALONG THE NAVET RIVER WHICH EVENTUALLY ENTERS THE NRL.



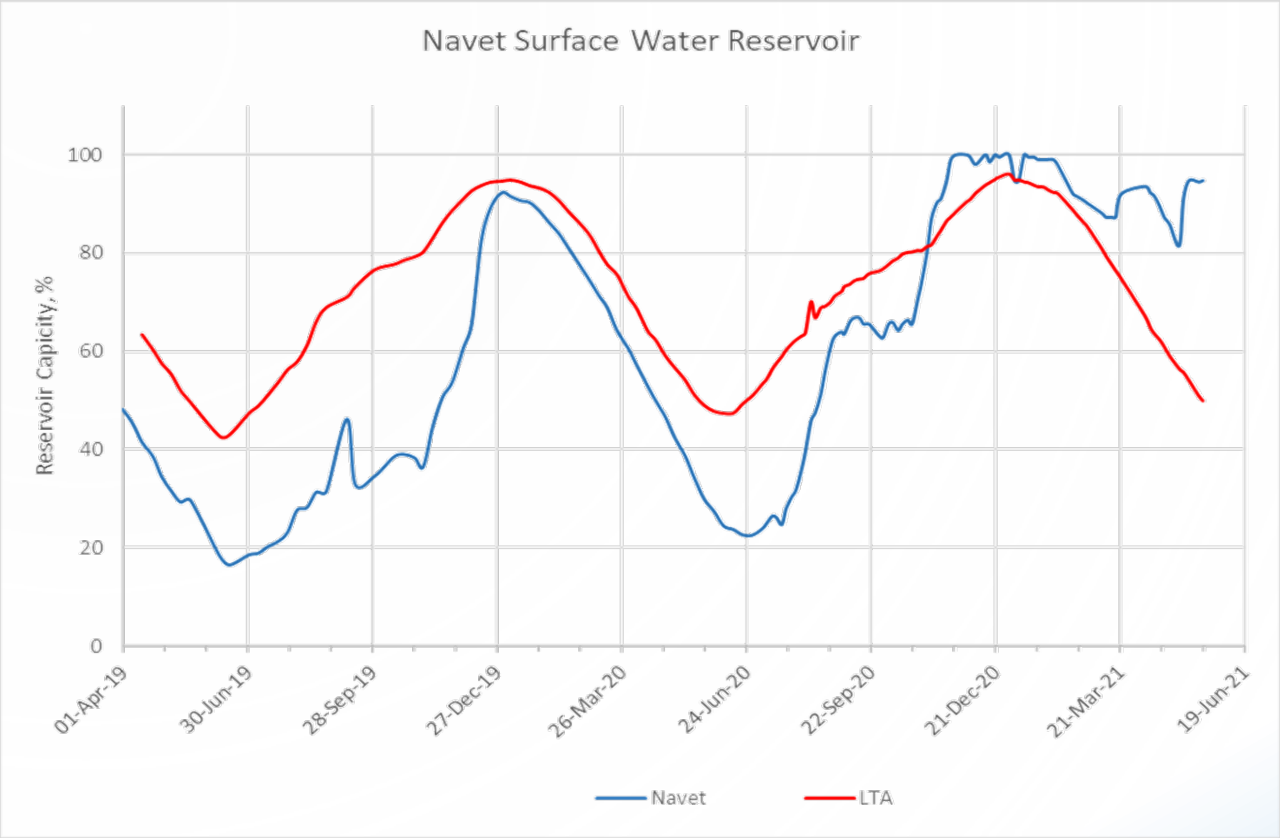
LAYOUT OF THE NAVET DAM

- THE NAVET DAM
  - CLAY CORE EMBANKMENT
  - 450M L-SHAPED
  - 60 M LONG STEPPED SPILLWAY



THE FUTURE OF NAVET

- A METEOROLOGICAL DROUGHT ANALYSIS PERFORMED BY BEHARRY ET.AL PUBLISHED 2019 USING 35 YEARS (1980-2014) OF MONTHLY TOTALS FROM FOURTEEN RAINFALL STATIONS ACROSS TRINIDAD IDENTIFIED DROUGHT VARIABILITY BETWEEN STATIONS IN THE NORTH AND CENTRAL REGIONS OF THE ISLAND.
- THE STATIONS AT THE ISLANDS THREE MAJOR DAMS ARENA, HOLLIS AND NAVET WERE AMONG THOSE ANALYSED.
- IT WAS FOUND THAT THE FREQUENCY OF METEOROLOGICAL DROUGHTS DECREASED AT THE HOLLIS RESERVOIR, WHILE AT THE NAVET RESERVOIR THERE WAS AN INCREASE, IMPLYING A DRYING PATTERN AND POSSIBLE ADVERSE EFFECTS ON THE WATER RESOURCES OF TRINIDAD.



Storage at the Navet Reservoir April 2019-May 2021

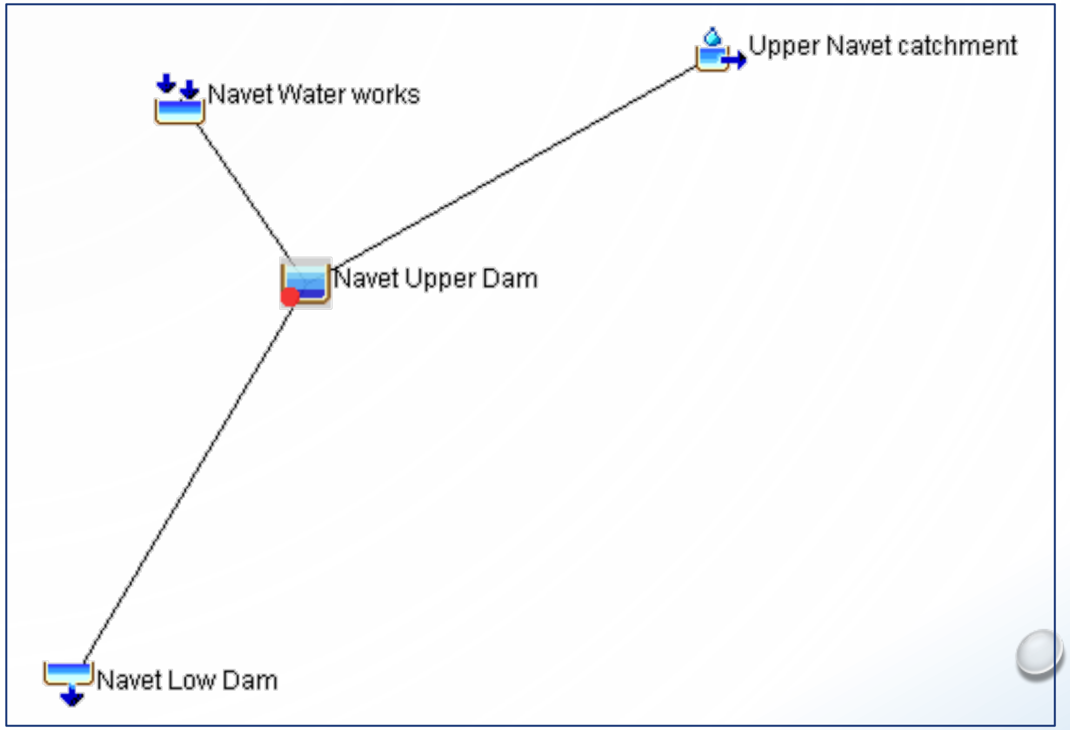
STUDY OBJECTIVES

- OBJECTIVES OF THE STUDY WERE
  1. TO CALIBRATE AND VALIDATE A HYDROLOGICAL MODEL OF THE NRS,
  2. TO EVALUATE THE HYDROLOGIC RESPONSE OF THE NRS TO A CLIMATE CHANGE SCENARIO
- STUDY PERIOD (2003-2009)
  1. CALIBRATION - 01JAN2003 – 31DEC2004 (2 YEARS)
  2. VALIDATION - 01JAN2005 – 31DEC2009 (5 YEARS)
  3. CLIMATE CHANGE SIMULATION 01JAN2030 31DEC2096 (67 YEARS)
- STUDY COMPLETED IN 2021

METHODOLOGY

MODELLING OF THE NRS WAS DONE USING THE HEC-HMS SOFTWARE AND CONSISTED OF FOUR MAIN PHASES.

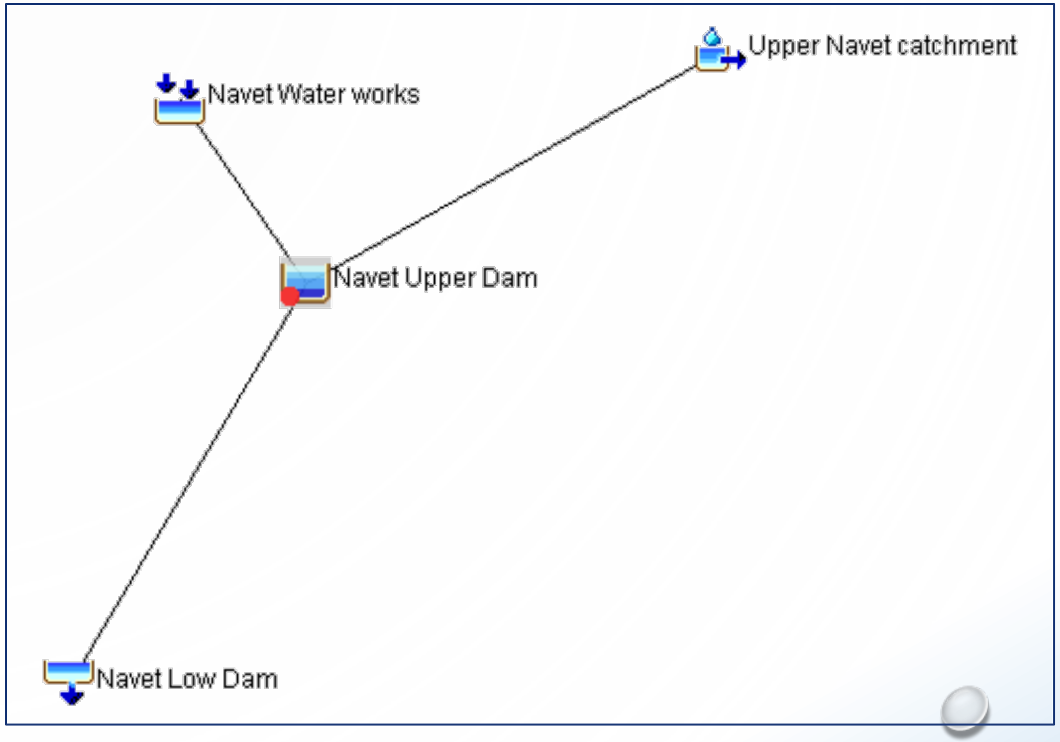
1. A CONCEPTUAL BASIN MODEL OF THE NRS WAS CONFIGURED WHERE HYDROLOGIC ELEMENTS WERE CREATED AND LINKED.
2. MODEL CALIBRATION WAS PERFORMED TO DETERMINE ITS SUITABILITY FOR REPRESENTING THE NRS.
3. MODEL VALIDATION
4. SIMULATION OF THE RESPONSE OF THE HYDROLOGIC SYSTEM TO FUTURE CONDITIONS



Basin Model of the NRS

MODEL CONFIGURATION

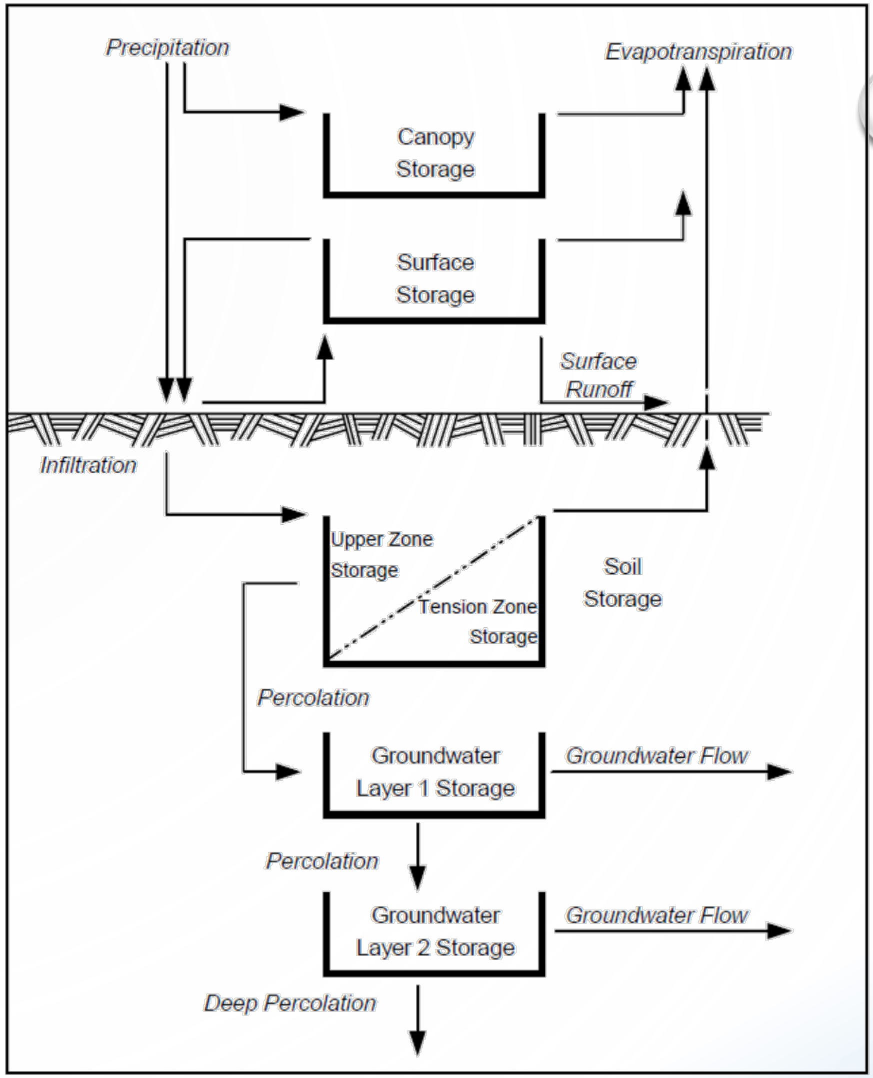
- HYDROLOGIC ELEMENTS WERE CREATED, PARAMETER VALUES WERE THEN ASSIGNED TO THESE ELEMENTS AND THE PROCESSES WHICH LINK THEM
- THERE ARE FOUR ELEMENTS IN THE BASIN MODEL :
    1. THE NAVET WATER WORKS ELEMENT WAS CREATED AS A SINK WHICH DRAWS WATER FROM THE NAVET UPPER DAM ELEMENT
    2. THE NAVET LOW DAM ELEMENT WAS CREATED AS A SOURCE SINCE ITS FUNCTION IS AS A WATER SUPPLY TO THE UPPER DAM ELEMENT.
    3. THE NAVET UPPER DAM WAS CREATED AS A RESERVOIR ELEMENT ACCEPTING INFLOWS FROM BOTH THE LOW DAM AND UPPER CATCHMENT. WATER LEAVES THE ELEMENT VIA PUMPING TO THE NAVET WATER WORKS AND A SPILLWAY WHICH IS NOT SHOWN IN THE BASIN MODEL.



Basin Model of the NRS

MODEL CONFIGURATION

4. THE UPPER NAVET CATCHMENT WAS CREATED AS A SUB-BASIN ELEMENT WHICH ALLOWS ITS HYDROLOGIC PROCESSES TO BE SIMULATED. THIS ELEMENT ALSO INPUTS FLOWS TO THE UPPER DAM AS A CATCHMENT OUTPUT.
   - INFLOW TO THE NAVET UPPER RESERVOIR WAS SIMULATED BY CONTINUOUS HYDROLOGIC MODELING OF THE UPPER CATCHMENT. THIS WAS DONE USING THE SOIL MOISTURE ACCOUNTING (SMA) ALGORITHM IN HEC-HMS TO ACCOUNT FOR THE WATERSHED'S SOIL MOISTURE BALANCE OVER A LONG-TERM PERIOD.



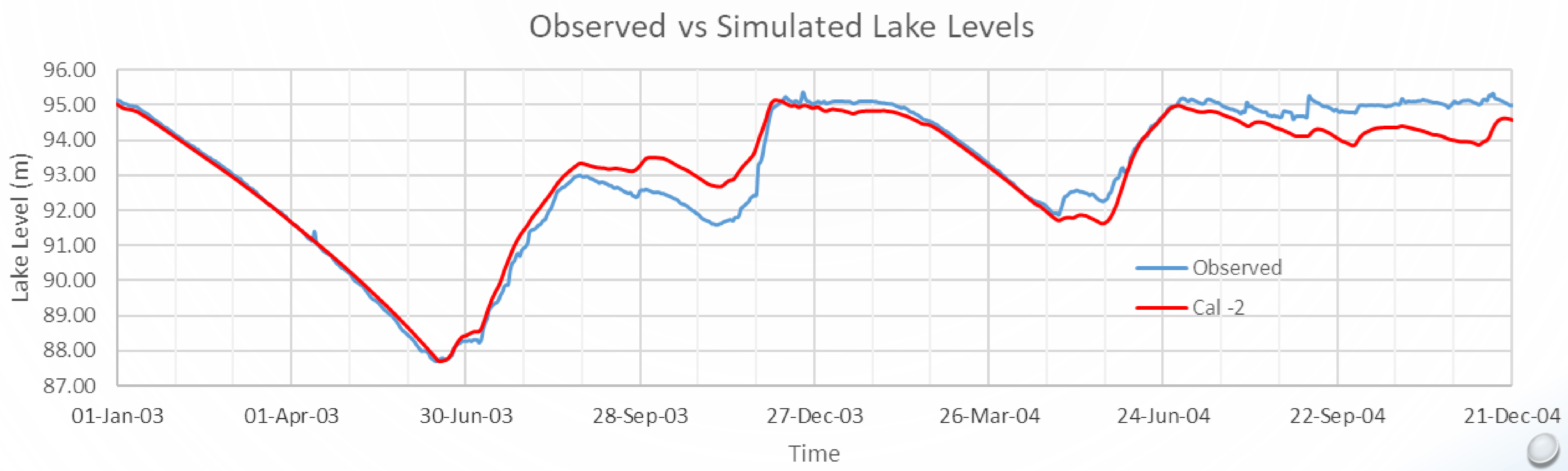
Conceptual Schematic Soil Moisture Accounting (SMA) Model (Bennett and Peters 2000)

CALIBRATION 01JAN2003 – 31DEC2004 (2 YEARS)

Storage Unit / Flow Component	Parameter	Lower range value	Upper range value	Typical	Values after Calibration
Canopy Storage	Max storage (mm)	1.6	2.2	2.0	2.0
	Crop coefficient	0	1	0.5	0.5
Surface Depression	Maximum storage (mm)	0.5	1.5	1.0	1.0
Soil Profile Storage	Maximum infiltration (mm/h)	4.13	8.13	6.13	**6.22**
	Soil storage (mm)	390	690	540	**450**
	Tension storage (mm)	390	540	470	**380**
	Soil percolation (mm/h)	0.75	1.16	0.89	**0.98**
GW1	Groundwater storage (mm)	50	200	100	100
	Groundwater percolation (mm/h)	0.75	1.16	0.89	0.89
	Groundwater coefficient (h)	50	500	200	200
GW2	Groundwater storage (mm)	50	200	100	100
	Groundwater percolation (mm/h)	0.75	1.16	0.89	0.89
	Groundwater coefficient (h)	100	1000	400	400
Transform method	Lag time (h)	7.1	7.1	7.1	**7.1**
	Peak factor	0.2	0.7	0.4	0.4
Imperviousness	Fraction of imperviousness (%)	0.5	1.5	1.0	1.0

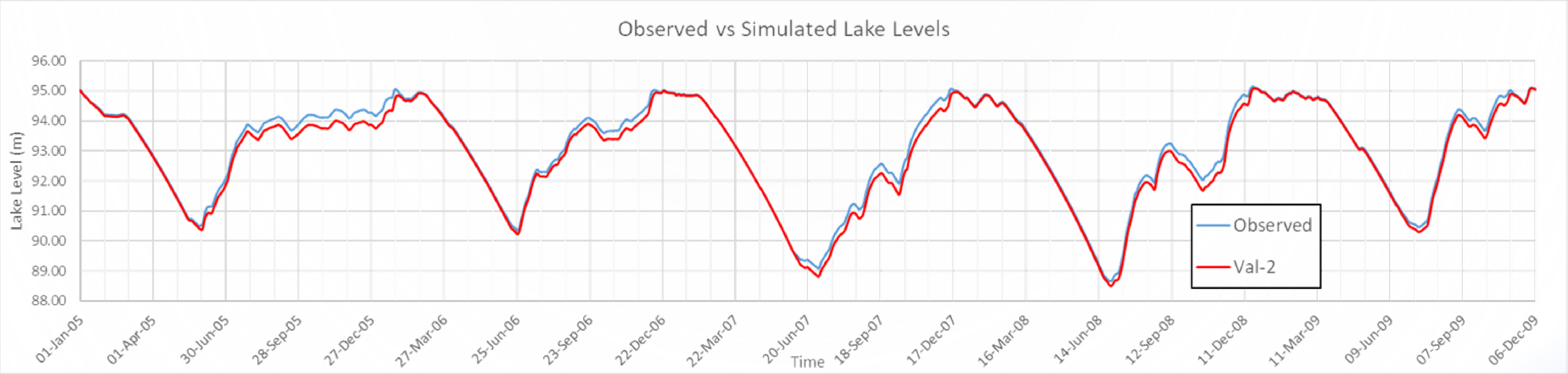
HEC-HMS Parameters and their ranges for the SMA (Wilson and Cooper 2017)

CALIBRATION 01JAN2003 – 31DEC2004 (2 YEARS)



CORRELATION COEFFICIENT 0.97

VALIDATION 01JAN2005 – 31DEC2009 (5 YEARS)



CORRELATION COEFFICIENT 0.995

MODELLING CLIMATE CHANGE

- THE DATA USED TO SIMULATE THE HYDROLOGIC SYSTEM RESPONSE TO CLIMATE CHANGE :
  - CONSISTED OF DAILY RAINFALL TOTALS AND ESTIMATED DAILY EVAPOTRANSPIRATION VALUES
  - **PRECIS** (PROVIDING REGIONAL CLIMATES FOR IMPACT STUDIES) DOWNSCALED THE GLOBAL MODEL **HADCM3** (HADLEY CENTRE COUPLED MODEL, VERSION 3) TO A REGIONAL LEVEL.
  - THE GLOBAL MODEL WAS SET UP FOR SPECIAL REPORT ON EMISSIONS SCENARIOS (SRES) A1B. THIS SCENARIO ASSUMES A FUTURE WORLD OF VERY RAPID ECONOMIC GROWTH, LOW POPULATION GROWTH AND RAPID INTRODUCTION OF NEW AND MORE EFFICIENT TECHNOLOGY.
- FOR THE NRS, THREE MODEL SIMULATIONS WERE USED:
  - **AENWH** WHICH REPRESENTS THE STANDARD UNPERTURBED MODEL FOR THE A1B SRES (WITH ORIGINAL PARAMETER SETTINGS)
  - **AEXSA** AND **AEXSK** WHICH ARE VARIATIONS ON THE **AENWH** MODEL

MODELLING CLIMATE CHANGE CON'T

- THE DIFFERENCES IN THE MODEL OUTPUTS TO THESE THREE SCENARIOS WERE DESCRIBED BY (WILSON AND COOPER 2017). THE AUTHORS COMPARED IDF CURVES FOR ALL THREE MODELS AND NOTED THAT
  - **AENWH**: SHOWS DECREASES IN INTENSITY OF EVENTS AT MOST DURATIONS, WITH GREATER DECREASES SHOWN FOR THE MOST EXTREME EVENTS
  - **AEXSA**: SHOWS INCREASES IN INTENSITY FOR ALL EVENTS, WITH THE LARGEST PROPORTIONAL INCREASES IN SMALLER MORE FREQUENT
  - **AEXSK**: SHOWS INCREASES IN INTENSITY FOR MORE FREQUENT EVENTS (2, 5 AND 10-YEAR), BUT DECREASES IN THE LESS FREQUENT, LARGER EVENTS (50 AND 100-YEAR)

MODELLING CLIMATE CHANGE CON'T

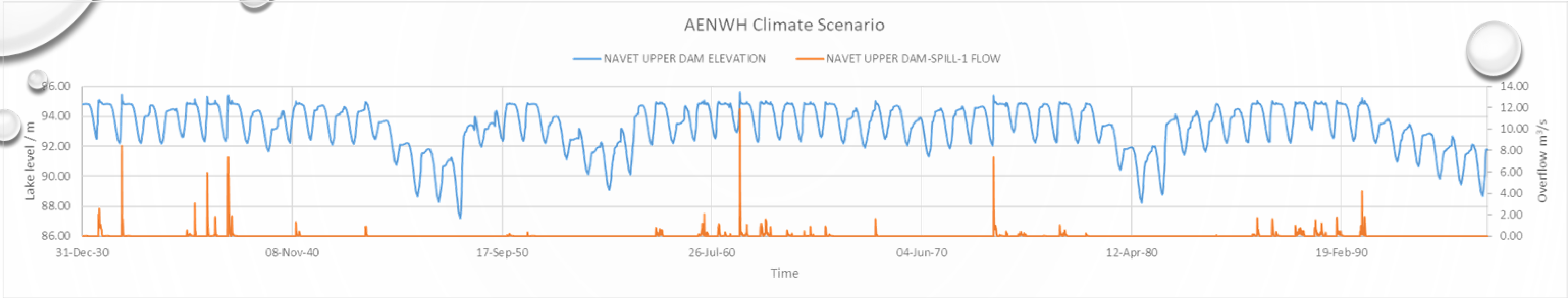
- FOR THE PURPOSE OF FUTURE OPERATION EXTRACTION FROM NRU WAS TAKEN TO BE 1.04 M^3/S WHICH CORRESPONDS TO THE YEARLY AVERAGE FOR THE 2003-2009 PERIOD. *(AN INCREASE IN DEMAND DUE TO POPULATION GROWTH WAS NOT FACTORED IN)*
- SIMILARLY, A HYPOTHETICAL TIME-SERIES FOR EXTRACTION FROM THE LOW DAM WAS REQUIRED. A CORRELATION WAS FOUND BETWEEN MONTHLY RAINFALL AND MONTHLY EXTRACTIONS FROM THE LOW RESERVOIR. A NEW TIME SERIES WAS GENERATED FOR THE PROPOSED LOW DAM PRODUCTION FOR THE PERIOD 2030 TO 2096 BY ASSUMING THAT THE MONTHLY PRODUCTION TOTALS REPEATS EVERY YEAR. *(A LIMITATION SINCE THIS ASSUMES THE LOW DAM WILL NOT BE AFFECTED BY CHANGES IN CLIMATE)*

RESULTS AND DISCUSSION

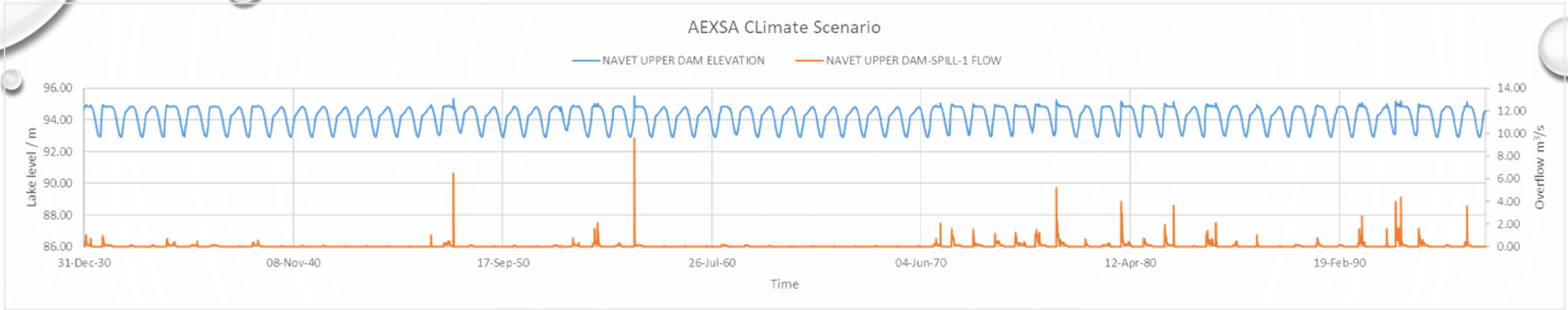
- FOR ALL THREE SCENARIOS, THE UPPER RESERVOIR WAS COMPLETELY DEPLETED BEFORE THE END OF THE SIMULATION PERIOD WHICH SUGGESTS THAT BASED ON CLIMATE CHANGE PREDICTIONS THE NRS CANNOT SUPPLY WATER AT ITS CURRENT RATE OF PRODUCTION.
- TO SIMULATE A REDUCTION IN RAW WATER EXTRACTION FROM THE UPPER DAM A NUMBER OF RAW WATER EXTRACTION TIME SERIES WERE GENERATED WITH EACH SUCCESSIVE RATE BEING 5% LOWER THAN THE PREVIOUS.

RESULTS AND DISCUSSION

- **AENWH** CLIMATE SCENARIO.
  - AT FULL PRODUCTION THE RESERVOIR WAS DEPLETED BEFORE THE END OF THE FIRST YEAR, 2030.
  - AT 95% PRODUCTION THE RESERVOIR EMPTIED BY THE END OF 2031.
  - PRODUCTION RATES WERE SUCCESSIVELY REDUCED BY 5% AND THE MODEL RUN UNTIL A VALUE WAS REACHED WHICH ALLOWED THE MODEL TO RUN UNTIL THE END OF THE SIMULATION PERIOD.
  - THE MODEL RAN TO COMPLETION FOR A DRASTICALLY REDUCED PRODUCTION RATE OF 0.73 M^3/S CORRESPONDING TO A REDUCTION IN PRODUCTION BY 30%.
- **AEXSA** AND **AEXSK** CLIMATE MODEL SCENARIOS.
  - IN BOTH INSTANCES, THE ULTIMATE PRODUCTION RATE WAS A REDUCED 0.63 M^3/S WHICH CORRESPONDS TO PRODUCTION RATE WHICH IS 60% OF PRESENT PRODUCTION (IN PRODUCTION BY 40%.).
- A STEPPED REDUCTION IN PRODUCTION RATE WAS CONSIDERED; HOWEVER, THE RESERVOIR WAS STILL DEPLETED OVER TIME BECAUSE OF THE CUMULATIVE EFFECT OF A PREVIOUS HIGHER PRODUCTION RATE. A MORE STRUCTURED APPROACH TO RESERVOIR MANAGEMENT AND OPERATIONS MAY RESULT IN HIGHER SUSTAINABLE PRODUCTION RATES *(THIS WAS NOT INVESTIGATED AT THIS TIME)*

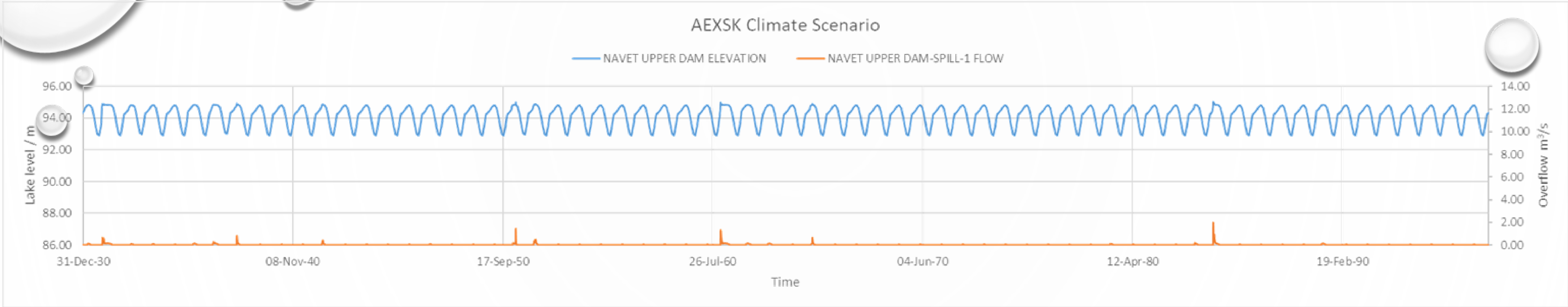


- REDUCTIONS IN THE SMALLER, MORE FREQUENT EVENTS FOR THE **AENWH** SCENARIO MEANT LONGER DRY PERIODS BETWEEN THE LESS FREQUENT LARGER EVENTS. THIS CAN BE SEEN IN THE MODEL RESPONSE ABOVE WITH A LARGER DIFFERENCE BETWEEN RESERVOIR LOW LEVEL AND HIGH LEVEL ELEVATIONS. THIS MAY INDICATE:
  - POSSIBLE LONGER PERIODS BETWEEN RAINFALL EVENTS (AND HIGH EVAPORATION LOSS). THE RESERVOIR SHOWS MORE FREQUENT OVERFLOW EVENTS THAN THE OTHER TWO SCENARIOS. THESE EVENTS ALSO CONTINUE FOR LONGER PERIODS WHEN THEY DO OCCUR. THIS OCCURS ALMOST YEARLY FOR THE PERIOD 2059 – 2065 AND CAN BE SEEN AS THE HORIZONTAL SECTIONS OF THE LAKE LEVEL PLOT ABOVE. THIS VOLUME OF EXCESS WATER WILL EVENTUALLY BE ROUTED TO THE LOWER RESERVOIR VIA THE NAVET RIVER.
  - THE RESERVOIR LEVEL ALSO REACHED VERY CLOSE TO IT LOW LEVEL MARK OF 82 M IN THE YEARS 2048, 2080, 2082 AND 2096. IT IS ALSO OBSERVED THAT THESE EVENTS OCCUR DURING PERIODS WHEN THERE ARE NO OVERFLOW EVENTS FOR A NUMBER OF YEARS PRIOR. THESE OBSERVATIONS ARE CONSISTENT WITH A REDUCTION IN THE MORE FREQUENT SMALLER RAINFALL EVENTS AND AN INCREASE IN THE LESS FREQUENT LARGER EVENTS.



- THE **AEXSA** CLIMATE SCENARIO SHOWED THE RESERVOIR GOING THROUGH A VERY CYCLIC FILLING AND EMPTYING PATTERN. THE RANGE OF LEVEL BETWEEN THE HIGHS AND LOWS ARE MUCH SMALLER THAN THOSE EXHIBITED FOR THE **AENWH** SCENARIO. THE RESERVOIR UNDER THESE CONDITIONS ALSO EXHIBITS A LOWER SUSTAINED SUPPLY.

- THIS CLIMATE MODEL SHOWED AN INCREASE IN BOTH LARGE AND SMALL EVENTS. THE RESULTS OF THE SIMULATION SHOW THAT THERE ARE MORE FREQUENT INSTANCES OF RESERVOIR OVERFLOW ALTHOUGH VERY SMALL IN THE FIRST 40 YEARS OF THE SIMULATION WITH MORE FREQUENT, LARGER OVERFLOW EVENTS AFTER 2071. THE MORE FREQUENT, SMALLER RAINFALL EVENTS ARE SUFFICIENT TO REFILL THE RESERVOIR AT A REDUCED RATE OF PRODUCTION PRIOR TO 2071. HOWEVER, POST 2071 THERE ARE LARGER AND MORE FREQUENT OVERFLOW EVENTS INDICATING A HIGHER WATER AVAILABILITY AND A POSSIBLE LARGER PRODUCTION RATE MAY BE SUPPORTED.



- THE AEXSK CLIMATE SCENARIO SHOWED AN INCREASE IN THE MORE FREQUENT SMALLER RAINFALL EVENTS AS WELL AS A DECREASE IN THE LESS FREQUENT LARGER RAINFALL EVENTS. THIS SCENARIO REPRESENTS THE MOST WATER SCARCE SCENARIO OF THE THREE. THE WATER LEVEL SIMULATED BY THE MODEL SHOWS A VERY CYCLIC FILLING AND EMPTYING OF THE RESERVOIR WITH A VERY SHALLOW ELEVATION RANGE BETWEEN. THIS TOGETHER WITH ALMOST NON-EXISTENT OVERFLOW EVENTS INDICATES THAT THE RESERVOIR RECEIVES JUST ENOUGH WATER FROM SMALL RAINFALL EVENTS TO PROVIDE A REDUCED SUPPLY, 60% OF PRESENT PRODUCTION.

CONCLUSIONS

- THE HEC-HMS SOIL MOISTURE ACCOUNTING ALGORITHM (SMA) HAS BEEN SHOWN TO ADEQUATELY REPRESENT THE CONTINUOUS MOVEMENT OF MOISTURE IN THE NAVET CATCHMENT AND TO ALLOW LONG TERM SIMULATION TO BE MADE.
  - (THE SIMULATED RESPONSE OF THE CATCHMENT TO PREDATED RAINFALL AND CLIMATIC CONDITIONS HAS SHOWN THAT THE MODEL CAN BE USED TO MAKE DECISIONS ON OPERATIONAL CHANGES AT THE DAM)
- (SRES) A1B SCENARIO : THE NAVET RESERVOIR WILL NOT BE ABLE TO ADEQUATELY SUPPLY THE WATER DEMANDS OF ITS DEPENDENT POPULATIONS FOR THIS SCENARIO.
  - THIS CAN MEAN ADDITIONAL SOURCES OF WATER MAY NEED TO BE BROUGHT ONLINE TO SATISFY INCREASING DEMANDS OF A GROWING POPULATION.
  - IT MAY SIGNAL THE NEED FOR IMPROVED CONSERVATION PRACTICES, NOT THE LEAST OF WHICH IS LEAK REDUCTION. AS THIS REPORT HAS SHOWN, THE FUTURE AVAILABILITY OF WATER IS THREATENED AND PRESENT PRODUCTION IS UNSUSTAINABLE.

FUTURE WORK

- THE CAPABILITY OF THE MODEL CAN BE ENHANCED BY THE TREATMENT OF THE LOWER RESERVOIR AND ITS CATCHMENT AS A HYDROLOGIC SYSTEM INSTEAD OF A WATER SOURCES. THIS WILL GIVE A COMPLETE VIEW OF HOW THE RESERVOIRS FUNCTION TO COMPLEMENT EACH OTHER.

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