

Laboratorio Parsons del MIT

# MASSACHUSETTS INSTITUTE OF TECHNOLOGY

## LABORATORIO RALPH M. PARSONS

## Una conferencia sobre el sector eléctrico colombiano

## SCHEDULING AND OPERATION OF THE COLOMBIAN ELECTRIC SECTOR

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**27 de octubre de 1986**

# SCHEDULING AND OPERATION OF THE COLOMBIAN ELECTRIC SYSTEM

I) MAIN SYSTEM ANALYSIS TECHNIQUES APPLIED IN THE ELECTRIC SECTOR OF COLOMBIA

II) RELATED RESEARCH WE ARE DOING AT THE GRADUATE PROGRAM IN WATER RESOURCES (NATIONAL UNIVERSITY OF COLOMBIA, MEDELLIN.)

# REFERENCES

## 1) PIONEER WORK

- ARVANITIDIS AND ROSING – PACIFIC NORTHWEST, USA
- KUIPER AND ORTOLANO – BRAZIL
- TURGEON
- PRONOVOST AND BOULVA

} HYDRO-QUEBEC, CANADA

## 2) STUDY AND RESEARCH CONDUCTED BY COLOMBIAN ELECTRIC SECTOR (UTILITIES AND CONSULTANTS)

## 3) ONGOING THESES AT THE NATIONAL UNIVERSITY OF COLOMBIA

PRIETO, ZAPATA, URIBE, TAMAYO

MESA, VALENCIA


CARIBBEAN SEA
PANAMA
VENEZUELA
MEDELLIN
BOGOTA
ECUADOR
PERU
BRAZIL
PACIFIC
OCEAN
AREA: 1,141,750 km²
(446,000 mi²)
POPULATION: 27 millions



HIGH MOUNTAINOUS AREA TO THE WEST (THE ANDES) CUT BY TWO DEEP LONGITUDINAL VALLEYS

HIGH MEAN ANNUAL PRECIPITATION

POTENTIAL CAPACITY FOR HYDROELECTRIC INSTALLATIONS : 93,000 MW

82 $\frac{KW}{KM^2}$

35 $\frac{KW}{INHAB.}$

# HYDRO POTENTIAL : 93,000 MW

TOTAL INSTALLED HYDRO CAPACITY { 4,518 MW (FEB. 1986) / 5% OF FEASIBLE INSTALLATION

- 30 PLANTS

- 15 RESERVOIRS

PLANTS WITH VERY HIGH HEADS AND DEEP UNDERGROUND POWER HOUSES ARE COMMON

WATER RESOURCES DEVELOPMENT HAS BEEN VERY IMPORTANT FOR ENGINEERING ADVANCEMENT IN COLOMBIA

## TOTAL INSTALLED CAPACITY

HYDRO : 4,518 MW (71.2%)

THERMAL : 1,831 MW (28.2%)

6,349 MW

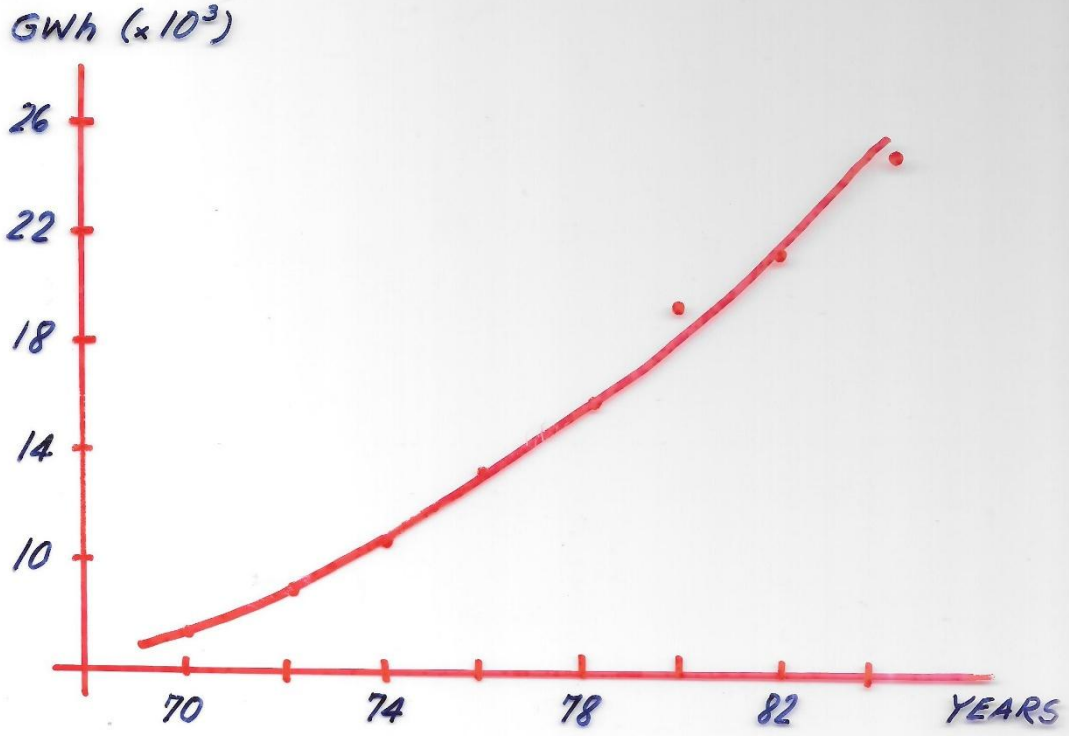
## TWO PROBLEMATIC QUESTIONS

- UNCERTAINTY OF HYDROLOGY
- ALLOCATION OF STORED WATER (ENERGY)

## THERMAL vs HYDRO

- IN THERMAL SYSTEMS, RELIABILITY INDEXES DEPEND ON CAPACITY AVAILABILITY
- IN HYDRO SYSTEMS, WATER DEFICITS HAVE A SIGNIFICANT IMPACT ON RELIABILITY

# ELECTRIC ENERGY CONSUMPTION




RATE OF GROWTH : 9% (ANNUAL AVERAGE)

GNP RATE OF GROWTH : 4.5%

# CHARACTERISTICS OF THE SECTOR

- ONE OF THE MOST MODERN IN ECONOMY
- NATIONALLY INTERCONNECTED
- CENTRALLY PLANNED. AN AGENCY IS RESPONSIBLE FOR

  SCHEDULING
  OPERATION PLANNING
  TRANSMISSION

- SYSTEM ANALYSIS TECHNIQUES ARE APPLIED

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ROGERS AND FIERING, WRR, AUGUST 1986

- GLOOMY PERSPECTIVE ABOUT THE USE OF SYSTEM ANALYSIS IN THE WORLD
- LESS DEVELOPPED COUNTRIES ARE MORE PRONE TO APPLY IT
- NO REPORT ON ELECTRIC SYSTEM PLANNING IN BRAZIL, COLOMBIA, ...

# I) MAIN TECHNIQUES APPLIED IN COLOMBIA

## A) SCHEDULING

DYNAMIC PROGRAMMING

## B) OPERATION (LONG-TERM)

STOCHASTIC DYNAMIC PROGRAMMING

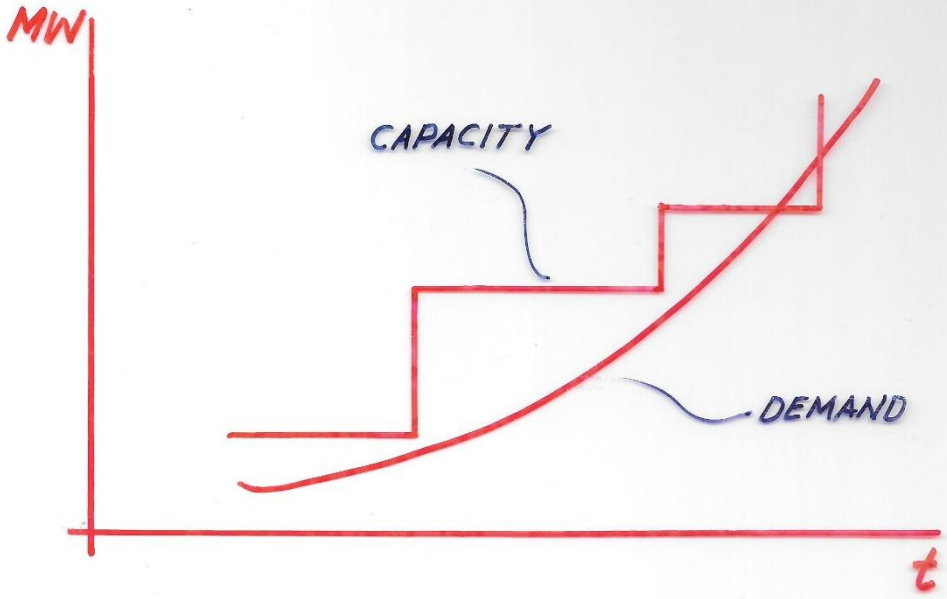
- CLASSICAL APPROACH
- SUCCESIVE APPROXIMATIONS
- AGGREGATION / DECOMPOSITION

OTHER SYSTEM ANALYSIS TECHNIQUES
(PROBABILISTIC MODELS, OPTIMIZATION, SIMULATION)
ARE WIDELY APPLIED TO OTHER PROBLEMS AS:

- ESTIMATION OF FUTURE ENERGY CONSUMPTION AND PEAK LOAD
- ENERGY PRODUCTION OF PROJECTS AND SYSTEMS
- RESERVE CAPACITY
- MEDIUM- AND SHORT-TERM OPERATION
- PREDISPATCH AND DISPATCH
- MAINTAINANCE PROGRAM
- DISTRIBUTION OF BENEFIT RESULTING FROM INTEGRATED OPERATION

# A) SCHEDULING (LONG-TERM : 15 YEARS)

"WHICH PLANTS, AND WHEN, SHOULD BE ADDED TO THE SYSTEM IN ORDER TO MEET THE DEMAND WITH AN ASSUMED RELIABILITY"




LARGE INVENTORY OF PLAUSIBLE PROJECTS

UNCERTAIN FUTURE { HYDROLOGY, CONSUMPTION }

# THE PROBLEM IS

MINIMIZE (INVESTMENT COST + OPERATION COST)

SUBJECT TO

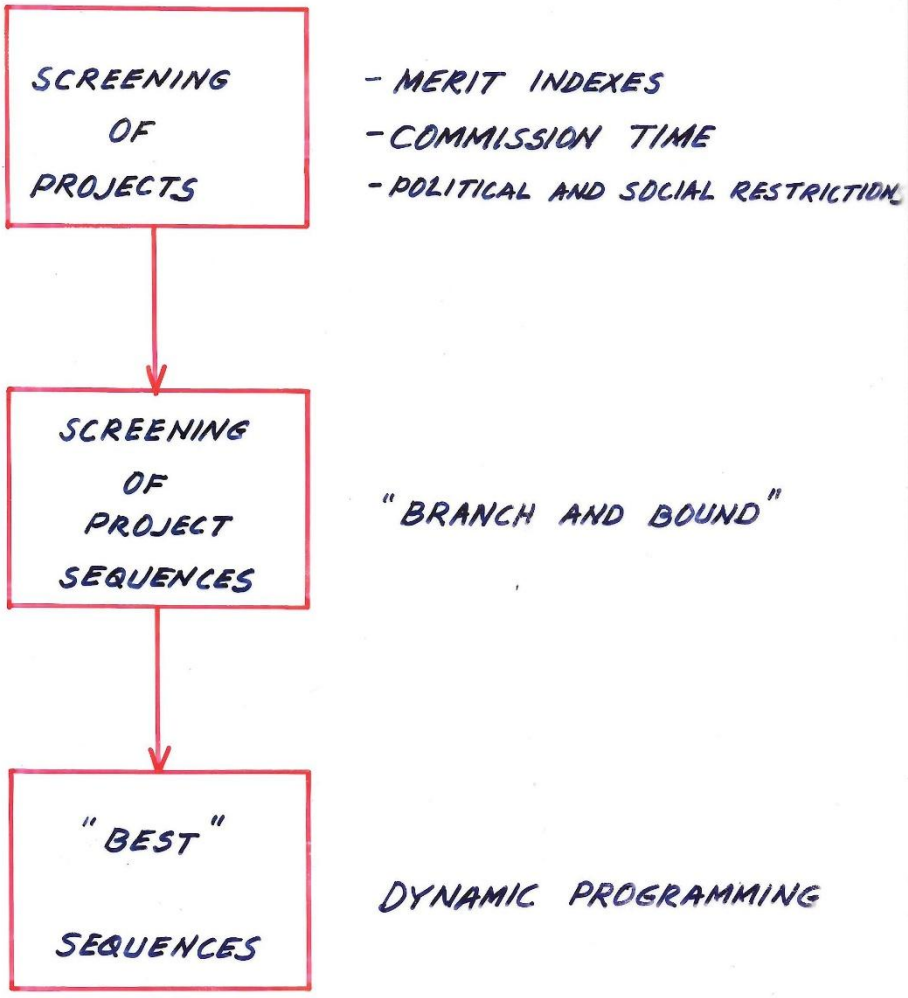
MEET ENERGY CONSUMPTION
MEET PEAK LOAD
} WITH ASSUMED RELIABILITY

INVESTMENT COST: CAPITAL EXPENDITURE TO CONSTRUCT NEW PLANTS

OPERATION COST:

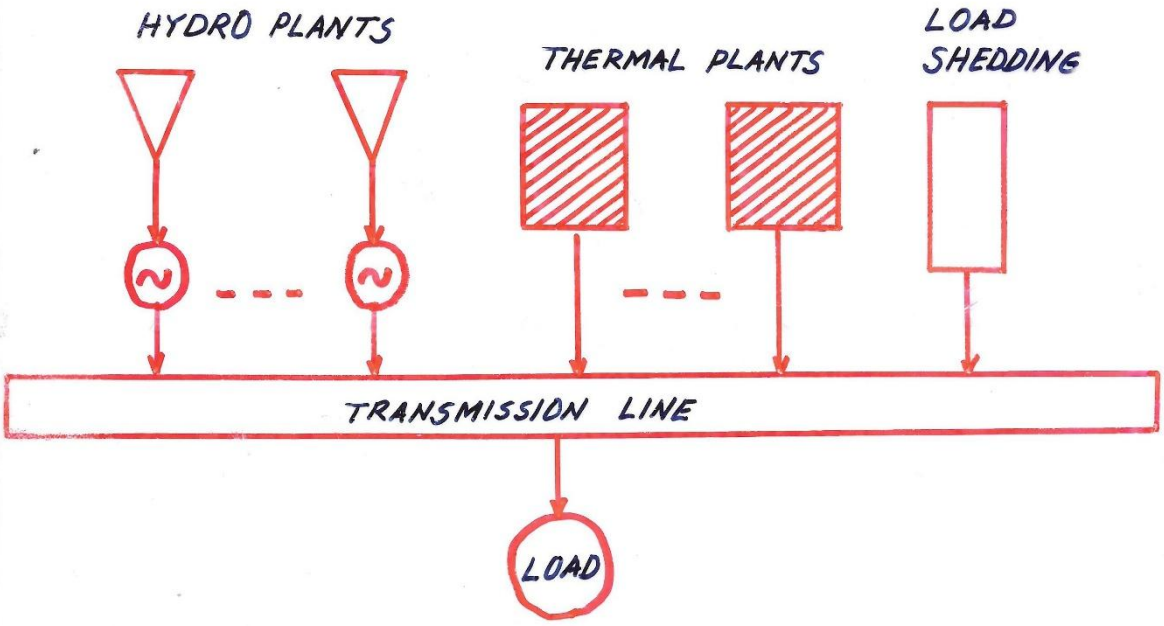
COST OF FUEL FOR THERMAL PLANTS
+
COST OF LOAD SHEDDING

OPERATION COST RESULTS FROM "OPTIMAL OPERATION" OF THE SYSTEM


SCREENING OF PROJECTS
- MERIT INDEXES
- COMMISSION TIME
- POLITICAL AND SOCIAL RESTRICTION
SCREENING OF PROJECT SEQUENCES
"BRANCH AND BOUND"
"BEST" SEQUENCES
DYNAMIC PROGRAMMING

# B) OPERATION OF THE SYSTEM

"HOW TO OPERATE THE SYSTEM
TO OBTAIN MINIMUM COST"




BASIC QUESTION: HOW TO MANAGE RESERVOIRS

- MORE RELEASE NOW SAVES FUEL OR LOAD SHEDDING NOW, BUT COULD INCREASE FUTURE COST

- INTERACTION BETWEEN PRESENT AND FUTURE DECISIONS

# PROBLEM ATTRIBUTES

## 1. STOCHASTICITY

INFLOWS, DEMAND, UNIT AVAILABILITY

## 2. TIME VARIABILITY

DEMAND IS NOT STATIONARY, SYSTEM STRUCTURE CHANGES WITH ADDITION OF NEW PROJECTS

## 3. MULTI-HORIZON

LONG-TERM EFFECTS (ENERGY SHORTAGES)

MEDIUM-TERM EFFECTS (MAINTENANCE PROGRAMS)

SHORT-TERM EFFECTS (FLOOD CONTROL)

## 4. LARGE SCALE

MULTIPLE RESERVOIRS

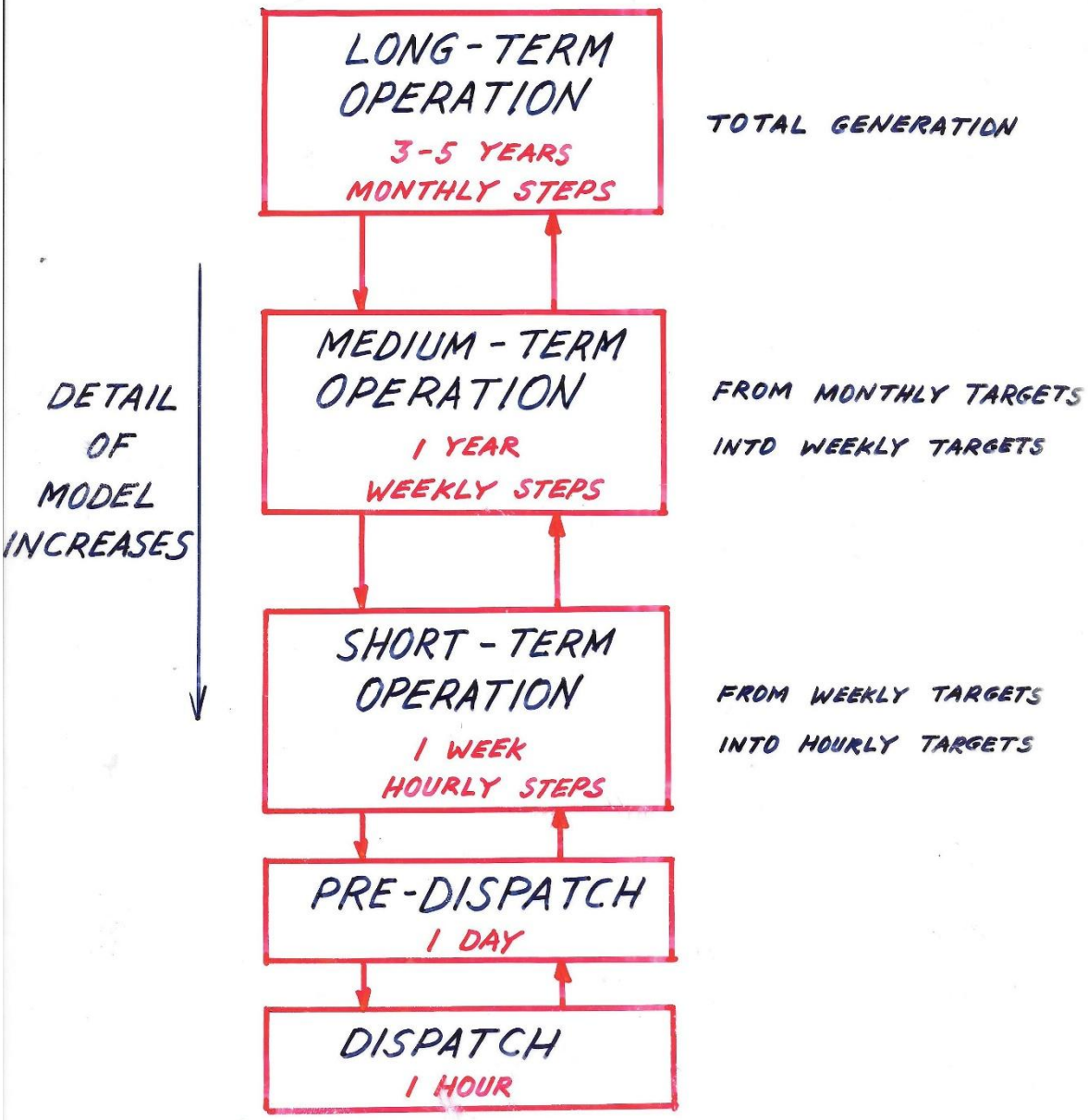
MULTI-PERIOD OPTIMIZATION

## 5. NON-LINEARITY

OBJECTIVE FUNCTION IS NOT LINEAR (THERMAL COST AND LOAD SHEDDING COST ARE NOT LINEAR)

HYDRO PRODUCTION IS OUTFLOW TIMES HEAD

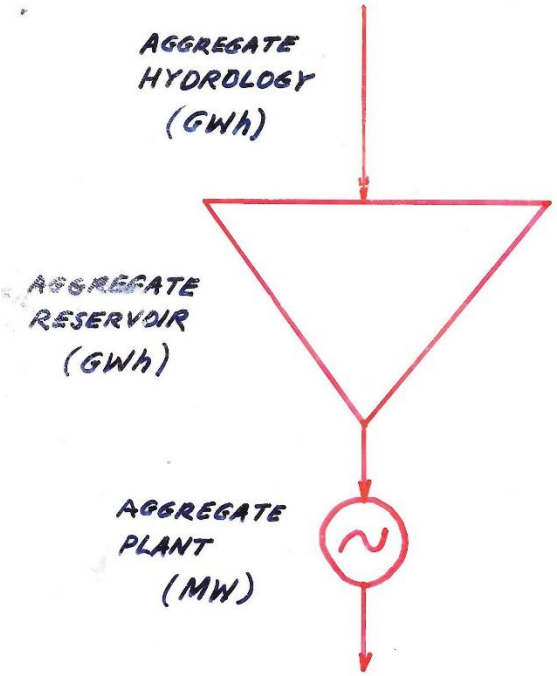
**TO TACKLE THE PROBLEM** { SEVERAL SUBPROBLEMS IN INTERCONNECTED TIME HORIZONS



# THE LONG-TERM OPERATION PROBLEM

STOCHASTIC DISCRETE DYNAMIC PROGRAMMING IS USED. TO AVOID THE "CURSE OF DIMENSIONALITY" WE PERFORM

## AGGREGATION OF HYDRO POWER SYSTEM

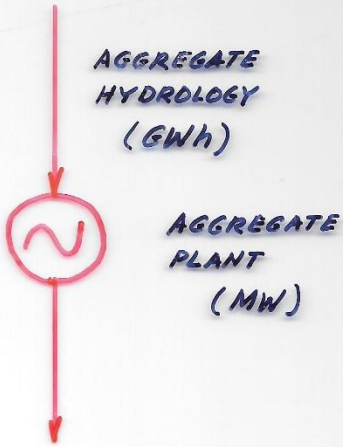



RESERVOIR CONTENT IS GIVEN IN UNITS OF "POTENTIAL ENERGY": SUM OF GENERATING CAPABILITY OF INDIVIDUAL HYDRO PLANTS

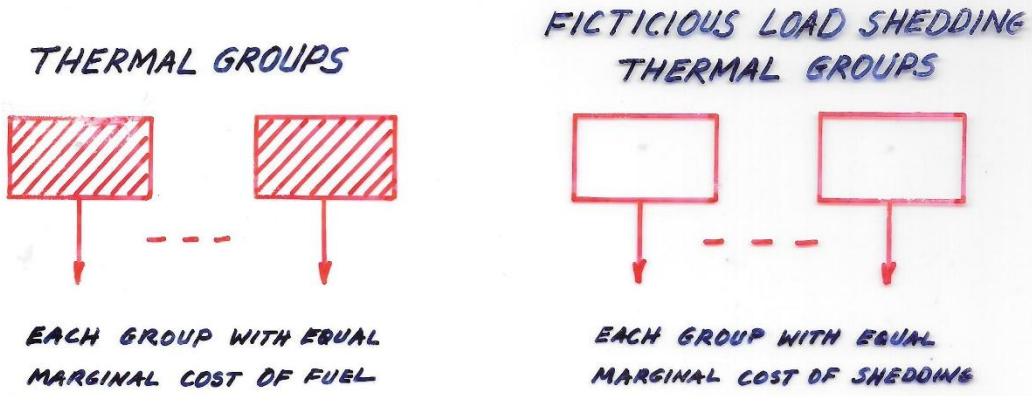
INFLOWS AND OUTFLOWS ARE ALSO GIVEN IN TERMS OF ENERGY

ONE-DAM, ONE-PLANT REPRESENTATION

## AGGREGATION OF RUN-OF-THE-RIVER PLANTS

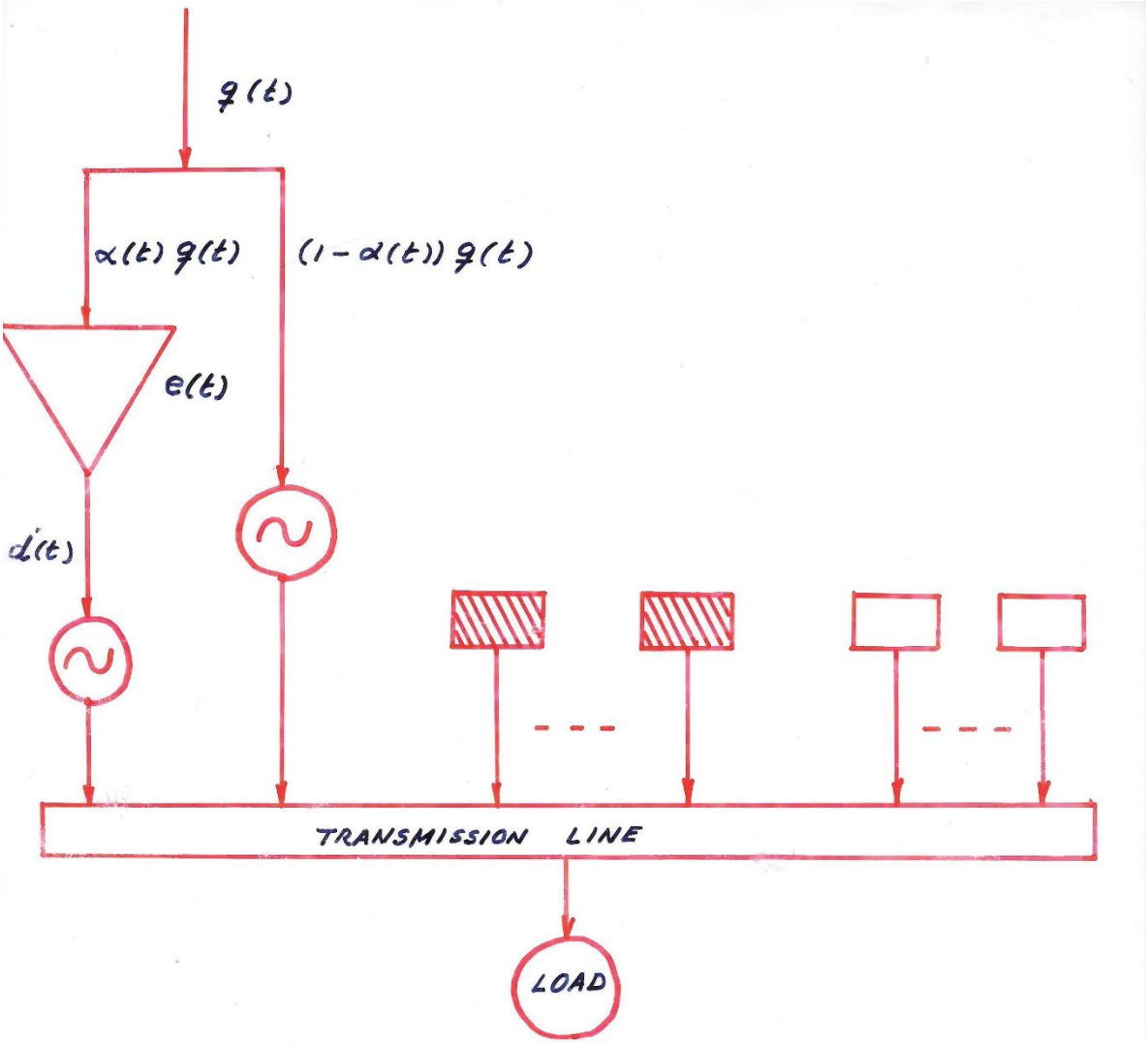



## AGGREGATION OF THERMAL PLANTS




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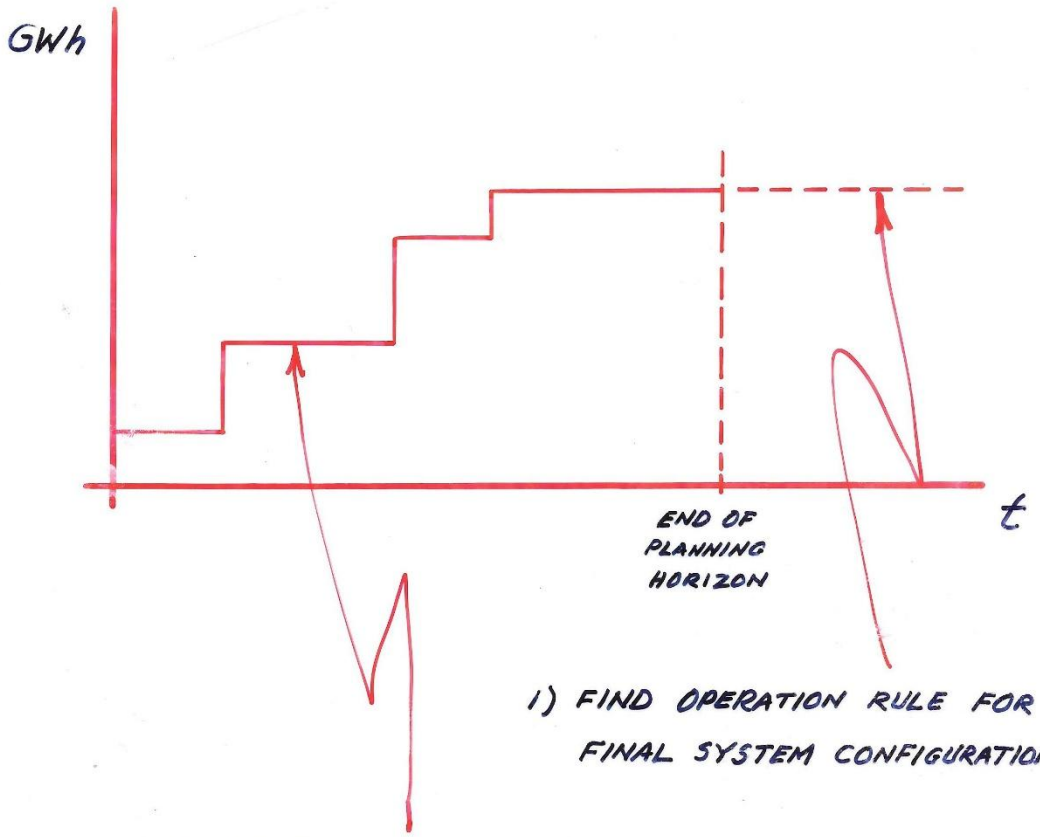
**ACTUAL SYSTEM** {
- 15 RESERVOIRS
- 30 HYDRO PLANTS
- 31 THERMAL PLANTS




STATE VARIABLES
- $e(t)$ : RESERVOIR CONTENT
- $q(t)$ : INFLOW

DECISION VARIABLE
- $d(t)$ : OUTFLOW FROM RESERVOIR

TO COPE WITH THE CASE OF A DYNAMIC SYSTEM




1) FIND OPERATION RULE FOR FINAL SYSTEM CONFIGURATION

2) THEN OPERATION RULE FOR THE DYNAMIC SYSTEM CAN BE FOUND BACKWARDS

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NEXT STEP: DISAGGREGATE OPERATION RULE

BELLMAN'S PRINCIPLE IS APPLIED TO

$$\underset{d}{\text{MINIMIZE}} \left\{ \text{COST NOW}(d) + \text{FUTURE COST}(e, q) \right\}$$

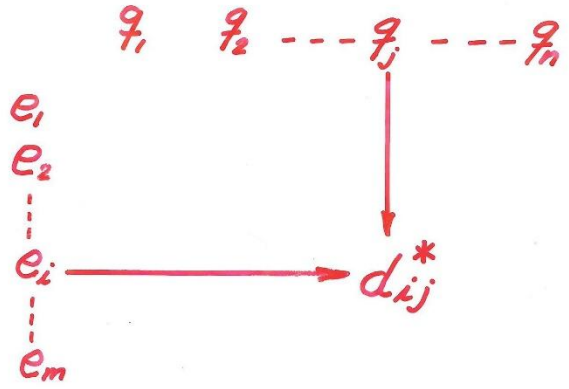
MARKOVIAN MODEL IS ASSUMED FOR HYDROLOGY

$$\left\{ \text{COST NOW}(d) + E\left[\text{FUTURE COST}(e, q)\right] \right\}$$

SUBJECT TO RESERVOIR AND PLANT CONSTRAINTS

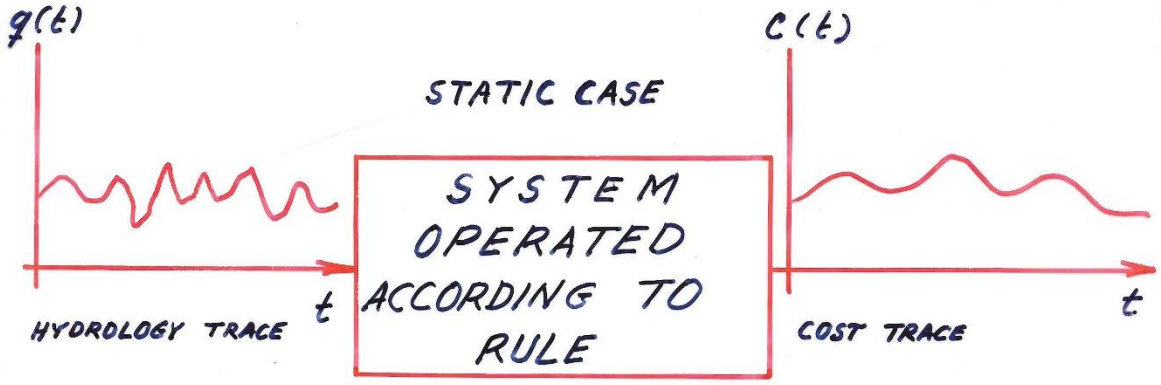
## OPERATION RULE

FOR EACH MONTH OF THE YEAR

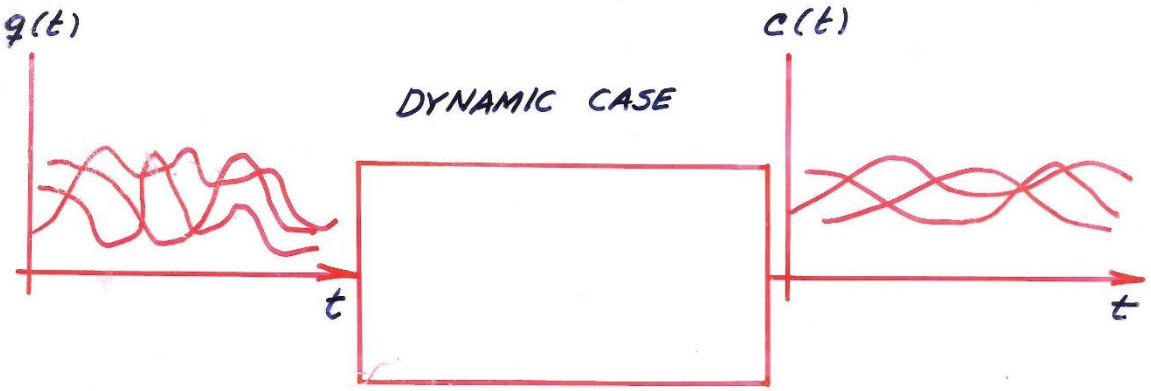



IN CONTROL THEORY: CLOSED LOOP STRATEGY

# ESTIMATING OPTIMAL COST BY SIMULATION




AVERAGE THROUGH OUTPUT TRACE
TO FIND EXPECTED COST




AVERAGE THROUGH OUTPUT ENSEMBLE AT EACH $t$
TO FIND EXPECTED COST AT $t$

## LIMITATION OF STOCHASTIC DISCRETE DYNAMIC PROGRAMMING

- IMPRACTICAL FOR MORE THAN ONE OR TWO RESERVOIRS

## LIMITATION OF THE AGGREGATION TECHNIQUE

- RESERVOIR REPRESENTATION IS NOT GOOD WHEN SOME RESERVOIRS HAVE SMALL REGULATING CAPACITY

- HYDROLOGY REPRESENTATION IS NOT GOOD WHEN REGIME IS NOT HOMOGENEOUS

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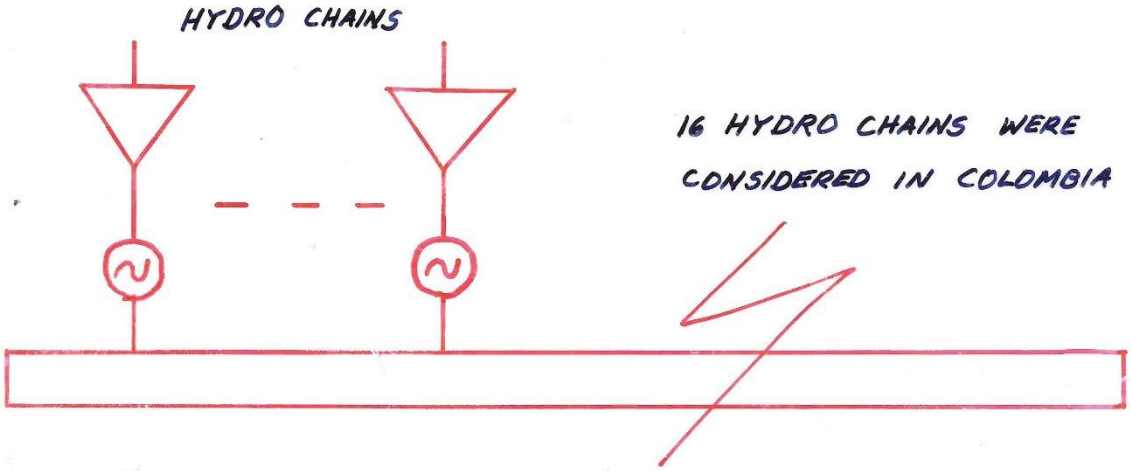
## NEW TECHNIQUES IN THE PROCESS OF BEING IMPLEMENTED IN COLOMBIA

A) STOCHASTIC DYNAMIC PROGRAMMING WITH SUCCESIVE APPROXIMATIONS

B) STOCHASTIC DYNAMIC PROGRAMMING WITH AGGREGATION/DECOMPOSITION

# A) STOCHASTIC DYNAMIC PROGRAMMING WITH SUCCESIVE APPROXIMATIONS

MAKE ONE AGGREGATION FOR EACH VALLEY (OR HYDRO CHAIN)




ONE-AT-A-TIME OPTIMIZATION OF EACH RESERVOIR

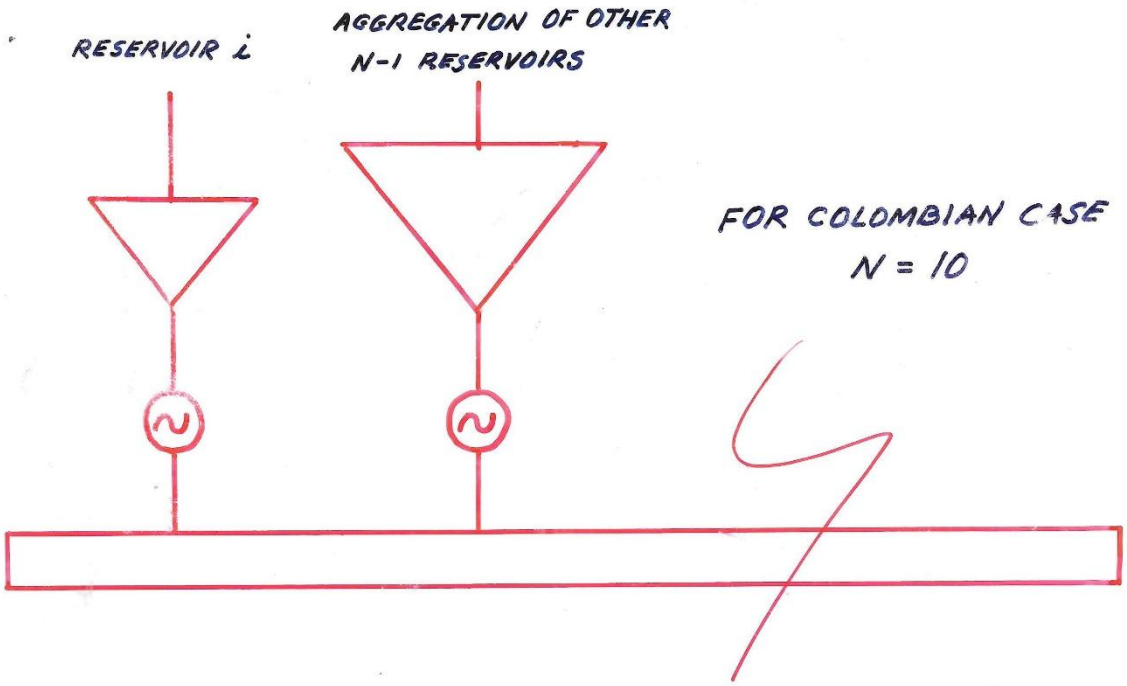
- OPERATION RULE OF OTHER RESERVOIRS IS INITIALLY ASSUMED AND THEREAFTER UPDATED. MEAN RELEASE OF THESE RESERVOIRS IS ALSO ASSUMED

- AFTER ALL RESERVOIRS HAVE BEEN OPTIMIZED, COMPARE NEW RULES WITH PRECEDING ONES. IF SIMILAR, STOP; IF NOT, REITERATE

OPEN-LOOP WITH LOCAL FEEDBACK

## B) STOCHASTIC DYNAMIC PROGRAMMING WITH AGGREGATION/DECOMPOSITION

INSTEAD OF SOLVING ONE PROBLEM FOR N RESERVOIRS, N TWO-RESERVOIR SUBPROBLEMS ARE SOLVED




FOR COLOMBIAN CASE
N = 10

CLOSED-LOOP WITH GLOBAL FEEDBACK

# II) RELATED RESEARCH AT THE GRADUATE PROGRAM IN WATER RESOURCES NATIONAL UNIVERSITY OF COLOMBIA (MEDELLIN)

FOR THE LONG-TERM OPERATION PROBLEM:

A) PERFORMANCE MEASURES OF THE SYSTEM

B) HOW SCARCE IS HYDROLOGIC INFORMATION?
HOW TO CHOOSE HYDROLOGIC MODEL?

C) DISAGGREGATION OF AGGREGATE OPERATION RULE

E) APPLICATION OF BENDERS DECOMPOSITION PRINCIPLE

THIS RESEARCH

- ADDRESSES REAL QUESTIONS OF COLOMBIAN SYSTEM
- HAS SOME SUPPORT OF ELECTRIC SECTOR

A) PERFORMANCE MEASURES OF THE SYSTEM

1. RELIABILITY. HOW OFTEN THE SYSTEM IS IN FAILURE

$$\text{PROB}\{\text{SYSTEM IS NOT IN FAILURE}\}$$

2. RESILIENCE. HOW QUICKLY THE SYSTEM RECOVERS FROM FAILURE

$$\text{PROB}\{\text{SYSTEM IS NOT IN FAILURE AT } t+1 \mid \text{SYSTEM WAS IN FAILURE AT } t\}$$

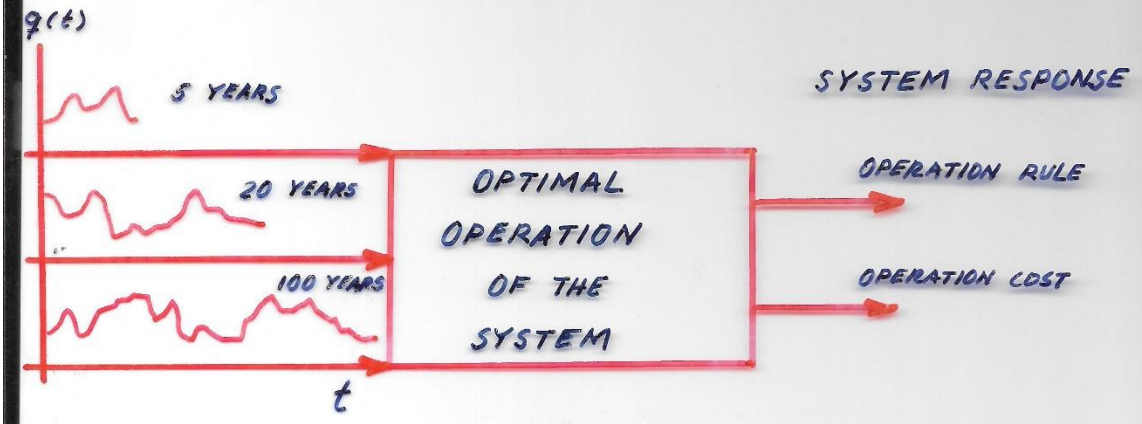
3. EXPECTED TIME THE SYSTEM IS IN FAILURE

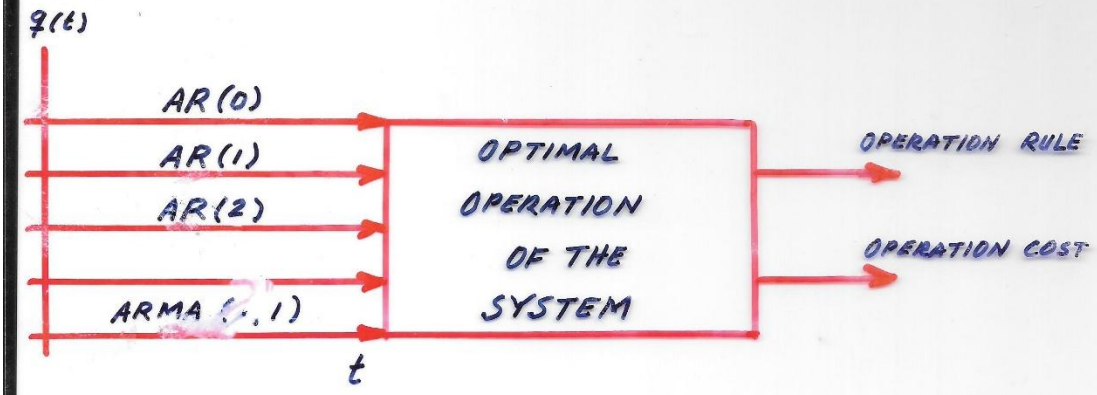
4. VULNERABILITY. HOW SEVERE THE CONSEQUENCES OF FAILURE MAY BE. WHAT ARE THE COSTS?

IT WAS FOUND THAT PERFORMANCE MEASURES CAN BE OBTAINED IN A CLOSED MANNER AFTER THE OPERATION RULE IS KNOWN

## B) HOW SCARCE IS HYDROLOGIC INFORMATION ?
## HOW IMPORTANT IS TYPE OF HYDROLOGIC MODEL ?

(ANSWERS FROM AN OPERATIONAL POINT OF VIEW )




HOW SENSITIVE IS SYSTEM RESPONSE TO

- VOLUME OF INFORMATION
- TYPE OF HYDROLOGIC MODEL

BRAZILIAN CASE, AS REPORTED BY
PEREIRA ET AL, WRR, MARCH 1984

FOR SOUTH AND SOUTHEAST REGIONS

ESTIMATED PEAK LOAD: 37,000 MW (1987)

QUESTION: WHAT IS THE RESERVE CAPACITY REQUIRED TO SUPPLY THE PEAK LOAD WITH A GIVEN RELIABILITY?

EXPECTED LOSS OF LOAD: 0.28 HOURS PER MONTH

TWO HYDROLOGIC MODELS, $M_1$ AND $M_2$, WERE USED

| | TOTAL INSTALLATION |
|---|---|
| $M_1$ → | 42,170 MW |
| $M_2$ → | 39,464 MW |
| | 2,706 |

THIS DIFFERENCE COSTS U.S.$ 950 MILLIONS (!)

# SUMMARY

1. PLANNING OF PREDOMINANTLY HYDRO POWER SYSTEMS REQUIRES SOPHISTICATED TECHNIQUES

   PROBABILISTIC MODELS
   STOCHASTIC OPTIMIZATION
   SIMULATION

2. DIFFERENCES BETWEEN THERMAL AND HYDRO SYSTEMS

3. REAL LIFE APPLICATION OF SYSTEM ANALYSIS

4. IN COLOMBIA, A NATIONAL AGENCY USES MODEL RESULTS FOR SCHEDULING AND OPERATION

5. PLANNING DECISIONS HAVE A SIGNIFICANT IMPACT ON NATIONAL ECONOMY

6. LARGE ROOM FOR COOPERATION BETWEEN PUBLIC UTILITIES AND ACADEMIA