CE718: Water Resources Systems Analysis
Course Project Report

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● Case Study - <u>**Water Scarcity in City of Valencia**</u>

The Júcar River Basin is located in the eastern part of the Iberian Peninsula in Spain, encompassing a total area of 22,300 km². The basin includes several key reservoirs (Alarcón, Contreras, and Tous) that provide water to the region, including the city of Valencia, Spain's third-largest metropolitan area. The basin also features the Albufera Natural Park, an important coastal wetland located just 10 km south of Valencia .

The water resources system operates in a tight balance between water demand and availability. The Júcar River is the main source of urban water supply for the city of Valencia and its metropolitan area (the third largest municipality in Spain). Water scarcity, irregular hydrology and over-exploitation of groundwater cause frequent and severe droughts with significant economic, social and environmental consequences. This situation is expected to be aggravated by the impact of (global) climatic and socio-economic changes and by increasing institutional obstacles resulting from political disputes between the two main riparian regions, Castilla-La Mancha (upper and middle basin) and Mancha (upper and middle basin) and Valencia(lower basin).

Project Focus :

- Developing optimal water allocation strategies that balance urban demands (Valencia), agricultural needs, and environmental requirements.
- Optimizing reservoir operations (Tous) to maximize water availability while maintaining ecological flows

- # Network diagram

(drawn from Canva)

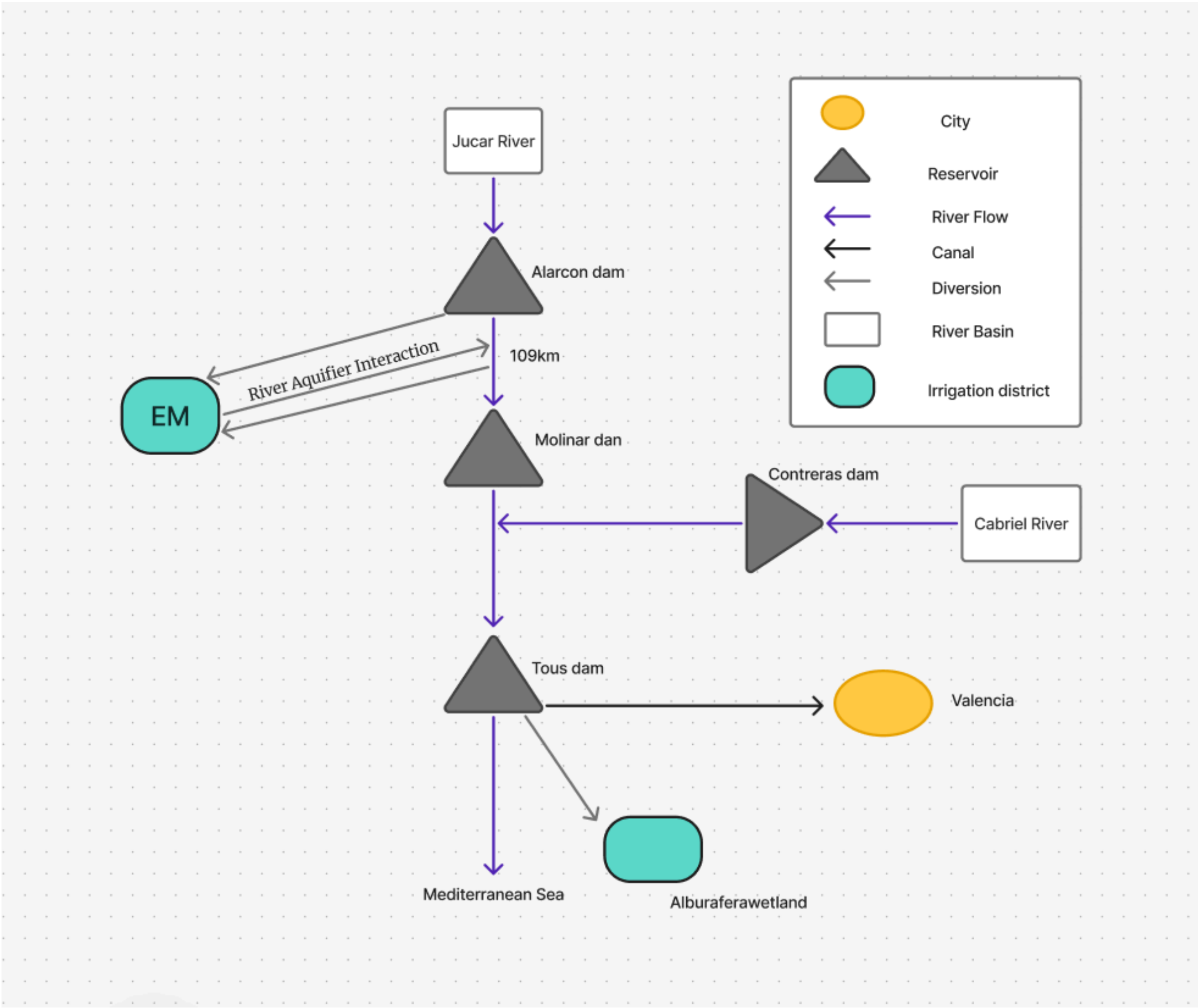

Figure 1 : Network diagram of the water resource system showing the Jucar river basin , Dam, rivers, cities and aquifers .

The diagram highlights the interconnections and flow paths, ensuring a comprehensive representation of the water resource system of ***Júcar River system*** .

- # Model Equations :
  - ## Decision Variables
    - **S(t)**: Storage volume at the beginning of month t (hm^3), for t = 1, 2, ..., 13
    - **R(t)**: Water release from the reservoir during month t (hm^3), for t = 1, 2, ..., 12

  - ## Objective Function

The objective is to maximize the total water release every month . This effectively maximizes water availability for all users while maintaining system constraints .

$$z = maximize \sum_{t=1}^{12} R(t)$$

- Constraints

1. Mass Balance Equations

$$S(t+1)=S(t)+Q(t)-R(t)-ET(t)$$ For t = 1, 2, ..., 12:

Where:

- Q(t) is the inflow to the reservoir in month t
- ET(t) is the evapotranspiration loss in month t

2. Storage Capacity Constraints

$$S(t) \leq K$$ For t = 1, 2, ..., 13:

Where K = 500 hm^3 represents the maximum storage capacity (Tous dam) of the reservoir.

3. Non-negativity Constraints

$$S(t) \geq 0$$, For t = 1, 2, ..., 13:

$$R(t) \geq 0$$, For t = 1, 2, ..., 12:

4. Demand Satisfaction Constraints

$$R(t) \geq D(t)$$, For t = 1, 2, ..., 12:

Where D(t) is the water demand in month t.

- Guarantees all water needs are met

5. Initial Storage Condition

$$S(1) = 250 \text{ hm}^3$$

- Sets realistic starting point (50% of capacity)

6. Final Storage Constraint (Sustainability)

$$S(13) \geq S(1)$$

- Ensures reservoir ends year at least as full as it started

- Timescale and Software used :
  - **Timescale**: The model was implemented at a monthly timestep over a one-year planning horizon (12 months), with an additional time point (t=13) for the final storage state.
  - **Solution Method**: The model was solved using LINGO/WIN64 21.0.37

- # Data Sources

Table 1 : Inflow of Dams , Aquifers and Wetland

	Inflow (in million cubic meter)						
Month	Alarcon Dam	Contreras Dam	Molinar Dam	Tous Dam	Transfers	Ground water	Total Supply
Jan	41	32	20.5	15	27	40	175.5
Feb	35	28	20	14	27	40	164
Mar	30	23	20.5	14.5	27	40	155
Apr	29.5	26.5	22	11	27	40	156
May	31	27.5	22.5	14	27	40	162
Jun	21	21.5	20.5	13.5	27	40	143.5
July	14	15	20	13	27	40	129
Aug	10	14	18	12.5	27	40	121.5
Sep	10	13	20	12	27	40	122
Oct	12	14.5	24	19.5	27	40	137
Nov	15	17	19	14.5	27	40	132.5
Dec	25	22.5	20	15	27	40	149.5

Source –

- https://hess.copernicus.org/articles/24/5297/2020/
- https://unece.org/sites/default/files/2021-05/S3_B1_Tous_Dam_break_case_study.pdf
- https://www.researchgate.net/publication/346888986_Risk_assessment_in_water_resources_planning_under_climate_change_at_the_Jucar_River_basin
- https://pure.iiasa.ac.at/id/eprint/17491/1/EngineeredRiversJucarFinal.docx
- https://www.chj.es/es-es/medioambiente/planificacionhidrologica/Documents/Plan-Hidrologico-cuenca-2021-2027/Libros-divulgativos/Libro_Divulgativo_PHJ15_21_English.pdf

- ## Water Demand Calculation:

The given data has been calculated by considering multiple factors and using the annual demand data for Valencia city to get the monthly demand.

- ## General Use:

Population of Valencia : 841,354
Average per capita water consumption in Valencia : 110 litres
Monthly per capita average : 110 litres * 30 days = 3.3 cubic meter
Average Monthly demand = 841,354 * 3.3 = **2.77 million cubic meter**

This average monthly demand fluctuates from one month to another due to multiple factors

Factors considered for variation:

- Temperature
- Tourism

Sources :

https://polaroo.com/en/articles/water-consumption-vacation-rental-sector-spain
https://thirdworldcentre.org/wp-content/uploads/2019/01/Water-demand-management-strategies-for-water-scarce-cities.pdf
https://en.wikipedia.org/wiki/Water_supply_and_sanitation_in_Spain
https://www.mdpi.com/2073-4441/13/23/3400

- ## Irrigation:

The agricultural landscape surrounding the city of Valencia is known as l'Horta de València ("the garden of Valencia"). It has approximately 25,000 hectares of cultivated land.

For calculating the irrigation demand, a lot of factors were considered as given below:

- Area distribution for different crops (also changes with season)
- Temperature
- Water requirements for different types of crops

Sources:

https://www.uv.es/horta-valencia-chair/en/history-landscape/landscape/crops.html
https://www.caixabankresearch.com/en/sector-analysis/agrifood/use-water-agriculture-making-progress-modernising-irrigation-and-efficient
https://www.fz-juelich.de/en/ibg/ibg-3/research-groups/modelling-terrestrial-systems/stochastic-analysis-of-terrestrial-systems/real-time-optimization-of-irrigation-of-citrus-fields-near-valencia-spain
https://hess.copernicus.org/articles/24/5251/2020/

- ## Industrial:

Valencia's industrial water demand is shaped by its key sectors—**automotive, chemicals, plastics, agri-food processing, and ceramics**—and their seasonal activity patterns.The following factors were considered:

- Different types of industries and their months with high and low workload
- Water requirements for different industries
- Climate

Sources:

https://www.investinspain.org/en/regions/comunidad-valenciana/industrias-destacadas

https://ris3cv.gva.es/en/rasgos-caracteristicos-del-contexto-economico-cv
https://en.wikipedia.org/wiki/Water_supply_and_sanitation_in_Spain
https://www.prologis.com/industrial-properties/spain/valencia

Table 2 : Water Demand for Valencia

	Demand (in million cubic meter)			
Month	General Use	Irrigation	Industrial	Total Demand
Jan	2.196	27	1.8	30.996
Feb	2.196	27	1.9	31.096
Mar	2.365	54	2.3	58.665
Apr	2.702	108	2.5	113.202
May	3.040	162	2.6	167.64
June	3.378	216	2.4	221.778
July	3.716	243	2.2	248.916
Aug	3.716	243	1.5	248.216
Sep	3.378	162	2.1	167.478
Oct	2.871	81	2.4	86.271
Nov	2.365	14	2.3	18.665
Dec	2.196	14	2.0	18.196

- ## Parameter Justification

  Maximum Capacity (K=500 hm³):
  Source :
  https://unece.org/sites/default/files/2021-05/S3_B1_Tous_Dam_break_case_study.pdf

- **Initial Storage (S(1)=250 hm³):**
  This value represents approximately 50% of maximum capacity, reflecting typical Mediterranean reservoir operations where storage fluctuates seasonally. This aligns with historical data showing Tous Dam operating at 51-62% capacity during similar periods. The model confirms this is sustainable as the ending storage returns precisely to this value.

Results and Discussions :

Month	1	2	3	4	5	6	7	8	9	10	11	12
Storage(hm^3)	250	211.9	335.8	422.1	453	433.4	339.2	201.3	57.6	0	41.9	149.3
Release(hm^3	205.5	31.1	58.7	113.2	167.6	221.8	248.9	248.2	167.5	86.3	18.7	42.1

- Release , Inflow and Demand curve :-

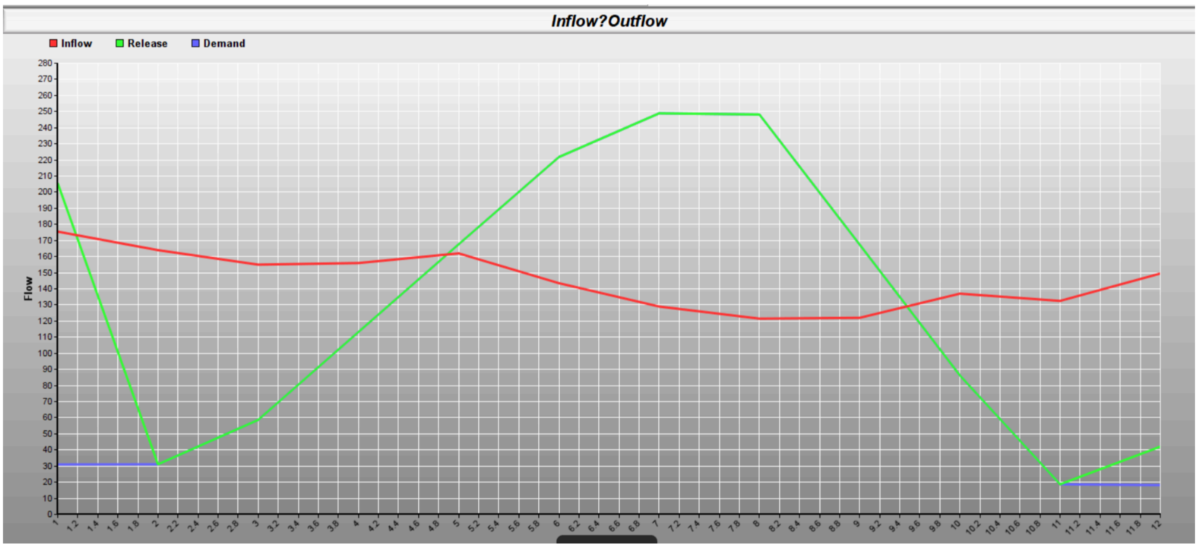

Figure 2 : Inflow , Release and Demand curve

- Storage in every month :-

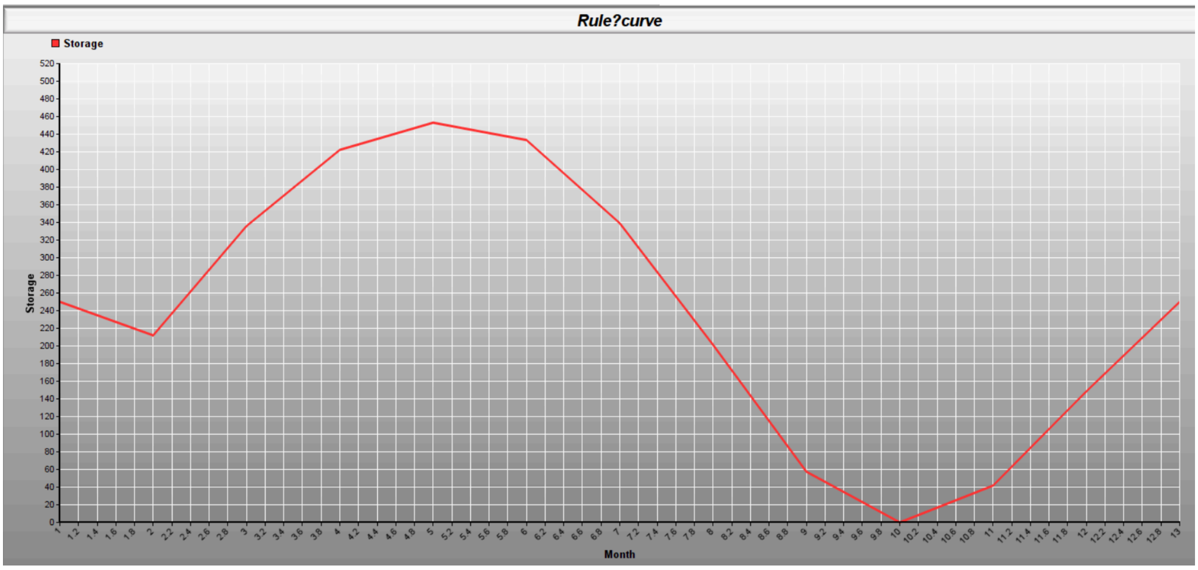

Figure 3 : Storage curve

- Storage analysis :
  - Storage Building Phase (Months 2-5):
    - Storage increases from 211.99 hm³ to peak at 453.03 hm³
    - This accumulation occurs during higher inflow months when demand is relatively low

- Drawdown Phase (Months 5-10):
    - Storage decreases steadily from 453.03 hm^3 to 0 hm^3
    - This coincides with high demand months (summer irrigation)
    - By month 10, the reservoir is completely depleted

      .
- Recovery Phase (Months 10-13):
    - Storage rebuilds from 0 hm^3 to 250 hm^3
    - Inflows exceed demands, allowing for replenishment

      .

- Release Decisions :
    - Month 1: Release (205.51 hm^3) greatly exceeds demand (30.996 hm^3)
        - Creates storage capacity for upcoming high inflow months
        - Prevents potential spillage later in the year
    - Months 2-11: Releases match demands exactly
        - Efficient use of water during these periods
        - No excess releases when storage is needed
    - Month 12: Release (42.06 hm^3) exceeds demand (18.196 hm^3)
        - Strategic release to achieve target end storage of 250 hm^3
        - Ensures the sustainability constraint is me

          .

- **Total Annual Release (objective function)** : 1,609.50 hm^3
    - Maximum storage (Month 5): 453.03 hm^3 (90.6% of capacity)
    - Zero storage (Month 10): Complete depletion requiring careful management
    - Maximum release (Month 7): 248.92 hm^3 coinciding with peak irrigation demand

• Conclusion :

The optimization model successfully maximizes beneficial water use (1,609.50 hm^3) while meeting all demands and ensuring year-end sustainability. Key findings include:

- The Mediterranean climate creates significant temporal mismatch between water availability and demand, necessitating large storage capacity.
- Storage depletion in month 10 indicates vulnerability to extended droughts, suggesting need for minimum storage requirements.
- Strategic releases in months 1 and 12 demonstrate the importance of anticipatory management rather than simple demand-matching.
- The optimal operation follows a pronounced seasonal cycle: store water during winter/spring for use during summer/fall irrigation season.

- Code

```
SETS:
    SET_S   /S1..S13/:        S;
    SET_R   /R1..R12/:        R;
    SET_Q   /Q1..Q12/:        Q;
    SET_ET  /ET1..ET12/:      ET;
    SET_D   /D1..D12/:        D;
    SET_T1  /1..12/:          Time;
    SET_T2  /1..13/:          Time2;
ENDSETS

DATA:
    Q     = 175.5 164    155    156    162    143.5 129    121.5 122    137    132.5 149.5;
    D     = 30.996 31.096 58.665 113.202 167.64 221.778 248.916 248.216 167.478 86.271 18.665 18.196;
    ET    = 8      9      10     12     14     16     18     17     12     9      7      6;
    Time  = 1      2      3      4      5      6      7      8      9      10     11     12;
    Time2 = 1      2      3      4      5      6      7      8      9      10     11     12     13;
ENDDATA

SUBMODEL OPERATION:
    K   = 500;
    MAX = @SUM(SET_R(t): R(t));
    @FOR(SET_S(t) | t #LE# 12:
        S(t+1) = S(t) + Q(t) - R(t) - ET(t);
        S(t+1) >= 0;
        S(t+1) <= K;
    );
    @FOR(SET_R(t):
        R(t) >= D(t);
    );
    S(1)    = 250;
    S(13) >= S(1);
ENDSUBMODEL

CALC:
    @SOLVE(OPERATION);
    @CHARTCURVE('Inflow-Outflow','Month','Flow',
                'Inflow', Time, Q,
                'Release', Time, R,
                'Demand', Time, D);
    @CHARTCURVE('Rule-curve','Month','Storage',
                'Storage', Time2, S);
ENDCALC
END
```