CE-718 WATER RESOURCES SYSYTEMS ANALYSIS
COURSE PROJECT REPORT

Group number: 17

Group members:

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PROBLEM STATEMENT

The Cauvery River Basin, which is of great importance to both Karnataka and Tamil Nadu, sustains agriculture, hydropower, and socio-industrial activities, experiences water disputes in drought conditions. An advanced approach of a particular type (simplified) for optimization problem dealing with water allocation inequality has been formulated by combining four reservoirs of Karnataka (Hemavathy, Harangi, Kabini, Hopper) and two reservoirs of Tamil Nadu (Mettur, Lower Bhavani) into a single system. The model makes it possible to swap water between the two states monthly, considering the various regional requirements (industrial, domestic, and irrigation) with the goal of achieving relatively equitable water apportionment in the region with sharpest contention of water use.

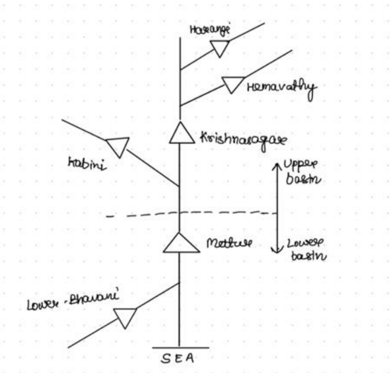


Figure 1: The six-reservoir system of the river basin under study.

NETWORK DIAGRAM

The network diagram above (Figure 1) shows, in a stage mark manner, the hydrological links between the reservoirs of the Cauvery River Basin, with the flow from the reservoirs in Karnataka (Harangi, Hemavathy, Krishnarajasagar and Kabini) to the reservoirs in Tamil Nadu (Mettur and Bhavani) and further to the ocean. For this study, and to concentrate on interstate water division, we have chosen to combine the four reservoirs from Karnataka into one and the two from Tamil Nadu into one as well. This aggregation still captures the important hydrological relationships, while providing a reasonable representation of the dynamics of water flow between the two states. The following diagram (Figure 2) depicts this consolidated network which was used in our optimization model

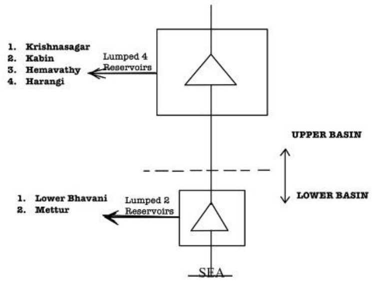


Figure 2 : Final Lumped Network Diagram

MODEL EQUATIONS

The model on the optimization on the Cauvery River Basin is done as a linear programming problem with an objective to increase net profit which is the economic benefit of water allocation.

Decision Variables

For each month (t = 1, 2, ..., 12):

$K_{\{ag,t\}}$: Water allocated to agriculture in Karnataka
$K_{\{in,t\}}$: Water allocated to industry in Karnataka (BCM)
$K_{\{hh,t\}}$: Water allocated to households in Karnataka (BCM)
$T_{\{ag,t\}}$: Water allocated to agriculture in Tamil Nadu (BCM)
$T_{\{in,t\}}$: Water allocated to industry in Tamil Nadu (BCM)
$T_{\{hh,t\}}$: Water allocated to households in Karnataka (BCM)
R_t: Water transferred from Karnataka to Tamil Nadu (BCM)
$S_{\{K,t\}}$: Storage in Karnataka's reservoir at the end of month t (BCM)
$S_{\{T,t\}}$: Storage in Tamil Nadu's reservoir at the end of month t (BCM)
$s_{\{K,t\}}$: Agricultural shortage in Karnataka (BCM)
$s_{\{T,t\}}$: Agricultural shortage in Tamil Nadu (BCM)
$s_{\{Ki,t\}}$: Industrial shortage in Karnataka (BCM)
$s_{\{Ti,t\}}$: Industrial shortage in Tamil Nadu (BCM)

Objective Function

Maximize total net benefit:

$$\max \sum_{t=1}^{12} \Big[w_K \cdot agri_{K,t} \cdot K_{ag,t} + w_T \cdot agri_{T,t} \cdot T_{ag,t} + w_K \cdot ind_K \cdot K_{in,t} + w_T \cdot ind_T \cdot T_{in,t} - transfer \cdot R_t + w_K \cdot storage_K \cdot S_{K,t} + w_T \cdot storage_T \cdot S_{T,t} - penalty_{agri} \cdot \left(s_{K,t} + s_{T,t}\right) - penalty_{ind} \cdot \left(s_{Ki,t} + s_{Ti,t}\right) \Big]$$

Where:

w_K, w_T: Weights for Karnataka and Tamil Nadu
$agri_{\{K,t\}}, agri_{\{T,t\}}$: Agricultural benefits per BCM
ind_K, ind_T: Industrial benefits per BCM
$transfer$: Cost per BCM of water transferred
$storage_K, storage_T$: Storage benefits per BCM
$penalty_{\{agri\}}$: Penalty per BCM for agricultural shortage
$penalty_{\{ind\}}$: Penalty per BCM for industrial shortage

Constraints

Mass Balance Constraints

$S_{\{K,t\}} = S_{\{K,t-1\}} + Inflow_{\{K,t\}} - Evap_{\{K,t\}} - K_{\{ag,t\}} - K_{\{hh,t\}} - K_{\{in,t\}} - R_t$
$S_{\{K,0\}} = InitStorage_K$
$S_{\{T,t\}} = S_{\{T,t-1\}} + Inflow_{\{T,t\}} - Evap_{\{T,t\}} + R_t - T_{\{ag,t\}} - T_{\{hh,t\}} - T_{\{in,t\}} - 0.28317$
$S_{\{T,0\}} = InitStorage_T$

Demand and Shortage Constraints

$K_{\{ag,t\}} + s_{\{K,t\}} = DemandAgri_{\{K,t\}}$
$T_{\{ag,t\}} + s_{\{T,t\}} = DemandAgri_{\{T,t\}}$
$K_{\{in,t\}} + s_{\{Ki,t\}} = DemandInd_{\{K,t\}}$
$T_{\{in,t\}} + s_{\{Ti,t\}} = DemandInd_{\{T,t\}}$

Service Level Agreements (SLA)

$K_{\{in,t\}} \geq sla_{\{ind\_min\}} \cdot DemandInd_{\{K,t\}}$
$T_{\{in,t\}} \geq sla_{\{ind\_min\}} \cdot DemandInd_{\{T,t\}}$
$K_{\{ag,t\}} \geq sla_{\{agri\_min\}} \cdot DemandAgri_{\{K,t\}}$
$T_{\{ag,t\}} \geq sla_{\{agri\_min\}} \cdot DemandAgri_{\{T,t\}}$

Environmental Flow

$R_t \geq env\_flow$
Where:

env_flow: Minimum environmental flow requirement

Household Water Supply

$K_{\{hh,t\}} \geq hh\_min_{\{K,t\}}$
$T_{\{hh,t\}} \geq hh_{min_{\{T,t\}}}$
Where:

$hh_{min_{\{K,t\}}}$:Minimum household water demand in Karnataka at time t
$hh_{min_{\{T,t\}}}$: Minimum household water demand in Tamil Nadu at time t

Reservoir Storage Capacity

$S_{\{K,t\}} \leq Capacity_K$
$S_{\{T,t\}} \leq Capacity_T$

Where:

$Capacity_K$: Maximum storage capacity of Karnataka reservoirs
$Capacity_T$: Maximum storage capacity of Tamil Nadu reservoirs

Bounds on Allocations

$0 \leq K_{\{ag,t\}} \leq DemandAgri_{\{K,t\}}$
$0 \leq T_{\{ag,t\}} \leq DemandAgri_{\{T,t\}}$
$0 \leq K_{\{in,t\}} \leq DemandInd_{\{K,t\}}$
$0 \leq T_{\{in,t\}} \leq DemandInd_{\{T,t\}}$

Where:

$DemandAgri_{\{K,t\}}$: Agricultural water demand in Karnataka at time t
$DemandAgri_{\{T,t\}}$: Agricultural water demand in Tamil Nadu at time t
$DemandInd_{\{K,t\}}$: Industrial water demand in Karnataka at time t
$DemandInd_{\{T,t\}}$: Industrial water demand in Tamil Nadu at time t

Non-negativity Constraints

$K_{\{hh,t\}}, T_{\{hh,t\}}, R_t, S_{\{K,t\}}, S_{\{T,t\}}, s_{\{K,t\}}, s_{\{T,t\}}, s_{\{Ki,t\}}, s_{\{Ti,t\}} \geq 0$

DATA SOURCES

Duration of Data Used:

The model is based on 12-month data of the year 2018(Jan-Dec). This is accounted for in the n_months = 12 parameter and the monthly charts (e.g., "Monthly Allocations & Transfer" and "Storage vs Capacity" graphs), which display results for a month marked from Jan to Dec. The data contains normal seasonality variations and hence is appropriate for a yearly water allocation policy.

Variables provided as data:

The following variables in the optimization model were supplied as pre-defined data inputs rather than being optimized:

Agricultural Demand (DemandAgri_K, DemandAgri_T):

- **Description:** Monthly water demand for agriculture in Karnataka and Tamil Nadu (BCM).
- **Source:** https://pmksy.gov.in/mis/Uploads/2016/20161219122752097-1.pdf https://www.niti.gov.in/sites/default/files/2019-01/Report%20Assessment%20of%20Water%20Foot%20Prints%20of%20India%27s%20Long%20Term%20Energy%20Scenarios_TERI%202017.pdf
- **Duration:** 12 months (January to December), for the year 2018.

Industrial Demand (DemandInd_K, DemandInd_T):

- **Description:** Monthly water demand for industry in Karnataka and Tamil Nadu (BCM).
- **Source:** https://pmksy.gov.in/mis/Uploads/2016/20161219122752097-1.pdf
- https://www.niti.gov.in/sites/default/files/2019-01/Report%20Assessment%20of%20Water%20Foot%20Prints%20of%20India%27s%20Long%20Term%20Energy%20Scenarios_TERI%202017.pdf
- **Duration:** 12 months (January to December), for the year 2018.

Inflow (Inflow_K, Inflow_T):

- **Description:** Monthly water inflow into the reservoirs of Karnataka and Tamil Nadu (BCM).
- **Source:** https://tnagriculture.in/ARS/home/reservoir
- **Duration:** 12 months (January to December), for the year 2018.

Evaporation (Evap_K, Evap_T):

- **Description:** Monthly water loss due to evaporation from Karnataka and Tamil Nadu reservoirs (BCM).
- **Source:** https://indiawris.gov.in/wris/#/evapotranspiration
- **Duration:** 12 months (January to December), for the year 2018.

Initial Storage (InitStorage_K, InitStorage_T):

- **Description:** Starting water volume in Karnataka and Tamil Nadu reservoirs at the beginning of the year (BCM).
- **Source:** https://tnagriculture.in/ARS/home/reservoir
- **Duration:** Single initial value applied at the start of the 12-month period.

Household Minimum Releases (hh_min_K, hh_min_T):

- **Description:** Minimum monthly water required for households in Karnataka and Tamil Nadu (BCM).
- **Source:** Defined as constant values (0.12 BCM for Karnataka and 0.10 BCM for Tamil Nadu) in the main code, based on domestic water supply standards.
- **Duration:** 12 months (January to December).

Reservoir Capacity (Capacity_K, Capacity_T):

- **Description:** Maximum storage capacity of Karnataka and Tamil Nadu reservoirs (BCM).
- **Source:** https://tnagriculture.in/ARS/home/reservoir
- **Duration:** Applies throughout the 12-month period as a static limit.

Economic Parameters (agri_USD_K, agri_USD_T, ind_USD, transfer_USD, storage_USD, penalty_agri, penalty_ind):

- **Description:** Monetary benefits and costs associated with agriculture, industry, water transfer, storage, and penalties for shortages (in ₹).
- **Source:** https://www.mdpi.com/2073-4441/1/1/5
- **Duration:** Applies across the 12-month period, with agricultural benefits varying monthly.

Environmental Flow (env_flow):

- **Description:** Minimum water flow required for environmental purposes (BCM/month).
- **Source:** Set as 0.05 BCM in the main code, based on ecological standards for the Cauvery River- https://www.mdpi.com/2073-4441/1/1/5
- **Duration:** Applies each month over the 12-month period.

RESULTS AND DISCUSSION

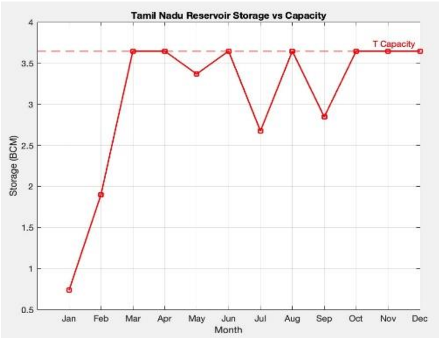


Figure 3: Tamil Nadu Reservoir Storage vs Capacity

Tamil Nadu Reservoir Storage vs Capacity:

- Monsoon fill: Storage rises from ~0.75 BCM in January to full capacity (≈3.65 BCM) by March–April due to northeast-monsoon inflows.
- Drawdowns during the dry season: Storage declines to ~3.35 BCM in May and goes as low as ~2.65 BCM in July before being refilled in August.
- Post-monsoon stability: A lesser drawdown in September (~2.85 BCM) is succeeded by consistent refilling to capacity during October to December, keeping buffers complete in anticipation of the winter cropping season.

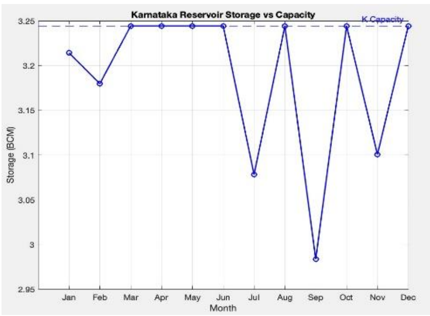


Figure 4: Karnataka Reservoir Storage vs Capacity

Karnataka Reservoir Storage vs Capacity:

- Early-year near-capacity: Reservoir begins at ≈3.22 BCM in January, reduces slightly in February (~3.18 BCM), then refills to its 3.245 BCM capacity by March–June.
- Monsoon fluctuation: A summer drawdown lowers storage to ~3.08 BCM in July (lower inflows + increased releases), but the southwest monsoon in August restores it to capacity.
- September trough & recovery: The lowest September drawdown (~2.98 BCM) is due to maximum agricultural releases; subsequently, inflows and prudent releases fill the reservoir to capacity in October, with small fluctuation in November before topping up in December.

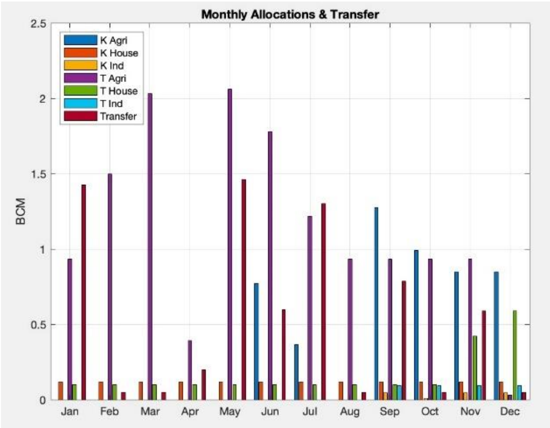


Figure 5: Monthly Allocations & Transfers

Monthly Allocations & Transfers:

- Transfers first: Tall red bars in Jan–Mar & May–Jul indicate that transferring water from Karnataka to Tamil Nadu is highest economic priority whenever K's inflow + storage permits.
- TN Agriculture second: Purple bars dominate early-year allocations (Mar–Jun), keeping pace with TN's cropping calendar.
- K Agriculture third: Blue bars come up Sep–Dec, after monsoon has replenished Karnataka's reservoirs.
- Household & Industry: Fixed minima thin orange/green/cyan bars every month—always exceeded, but never "compete" for additional water.

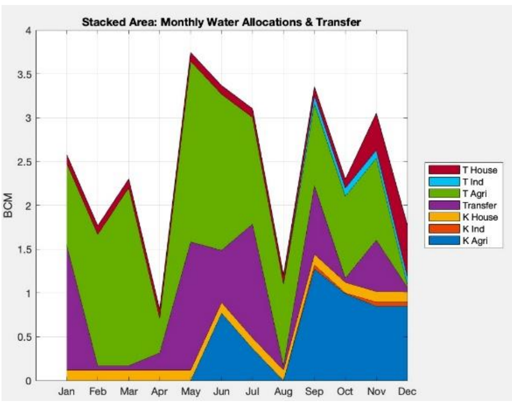


Figure 6: Total Monthly Releases (Stacked Area)

Total Monthly Releases (Stacked Area)

- Two peaks: May (~3.7 BCM) (TN agriculture + transfers) and September (~3.3 BCM) (K agriculture + TN agriculture) crest Releases.

- Lean months: April (~0.7 BCM) and August (~1.1 BCM) record only required household/industry flows - no transfers or additional cropping.
- Layer order = value order: Top → Transfers; followed by TN Agri (green); then K Agri (blue); with industry/household at the bottom.

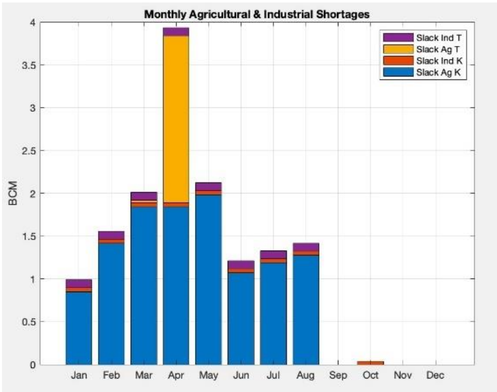


Figure 7: Monthly Agricultural and Industrial Shortages

A cursory look at monthly slack (unfulfilled) demand shows how the optimizer distributes limited water under competing crop, industrial and environmental demands:

Jan–Feb (Pre-monsoon Rabi):

- Agriculture in Karnataka suffers the most (blue bars), as limited reservoir storage necessitates cuts to rabi irrigation.
- Industrial slack in both states is negligible, as agri penalties prevail.

Mar–Apr (Samba Peak & Kharif Prep):

- Two agricultural shortages appear: Tamil Nadu's samba (yellow) and Karnataka's kharif buildup (blue) cannot be met in full
- April indicates the greatest combined slack (~4 BCM), an indication of the conflict between high-value crop periods prior to monsoon inflows.

May–Aug (Monsoon Onset & Kharif):

- Inflows rise, Karnataka's Agri slack gradually reduces and is gone by July.
- Tamil Nadu no longer has any Agri shortfall, since its second crop window is lower-priority.

Sep–Dec (Post-monsoon & Rabi Closure):

- No slack in September and Nov–Dec, which means all demands are coverable once peak agricultural windows shut.
- A small industry shortage is visible in October (Karnataka) when remaining water prefers household and storage needs.
- This trend emphasizes the urgent need for pre-monsoon allocation and the high price of unsatisfied crop demand, steering monthly release tactics to reduce farming shortages.

Figure 8: Monthly Industrial Profit

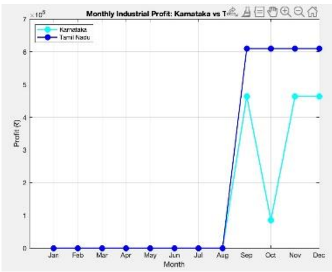
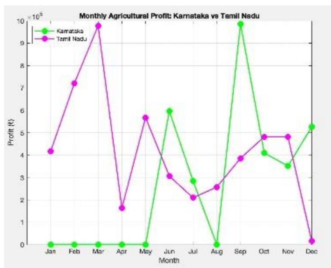


Figure 9: Monthly Agricultural Profit



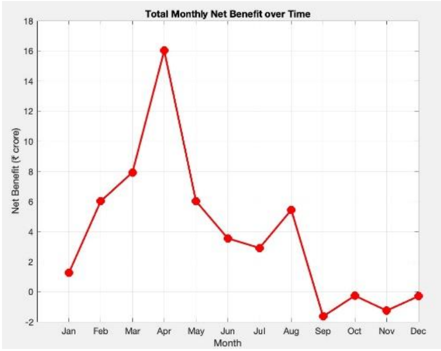


Figure 10: Monthly Net Benefit

Net Benefit Profile

- April Peak (₹16 cr): Triggers by Tamil Nadu irrigation with high-value crops at close of its samba season; surplus inflows are profitably diverted.
- March & August Bumps (₹8 cr, ₹5.5 cr): Align with critical planting windows in TN (Mar) and combined crop windows in both states (Aug).
- Mid-Year Trough (May–Jul, ₹6 → 2.8 cr): Storage and environmental minimums constrain releases.
- Negative Trough (Sep, Nov): Off-season agriculture still commands heavy slack-penalties, overshadowing modest industrial/transfer gains.

Sectoral Insights

Agriculture:

- Tamil Nadu dominates Jan–Apr (highest samba yields).
- Karnataka dominates Jun–Sep (kharif cropping); shoulder months witness shared allocations.

Industry:

- Zero profit until the post-monsoon, since unmet-Agri penalties compel complete agricultural servicing.
- Sep–Dec profits when agri windows finish; Tamil Nadu beats Karnataka because of model weights.

Principal Trade-offs

- Seasonal Coefficients: Large crop-season-benefit coefficients steer water to agriculture ahead of industry.
- Slack Penalties: Huge penalties for unmet crop demand almost withdraw industrial allocations during peak seasons.
- Reservoir & Flow Constraints: Environmental flow requirements and storage targets moderate mid-year allocations.

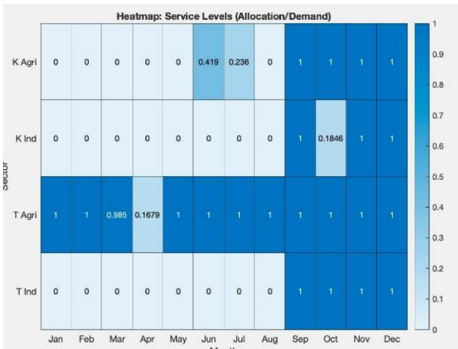


Figure 11: Heatmap of Service Levels (Allocation/Demand) Across Sectors and Months

- Tamil Nadu agriculture is mostly fulfilled year-round, with a dip in April; Karnataka agri gets full supply post-monsoon.
- Industry in both states is deprioritized until surplus water is available.

- The model favors penalties over low-profit allocations in off-season.

Sector	Jan–Apr	May–Aug	Sep–Dec
K Agri	0 % service	42 % (Jun), 24 % (Jul), 0 % (Aug)	100 %
K Ind	0 %	0 %	100 % (Sep), 18 % (Oct), 100 % (Nov–Dec)
T Agri	100 % (Jan–Mar), 99 % (Mar), 17 % (Apr)	100 %	100 %
T Ind	0 %	0 %	100 %

Table 1: Heatmap interpretation table of different sectors

CONCLUSION

The tailored linear-programming model of the Karnataka–Tamil Nadu basin has illustrated the following capabilities:

Maximized Economic Return

- Generates an overall annual net benefit of ₹ 45.6 crore by distributing water optimally between agriculture, industry, households and inter-basin transfers.

Integrated Hydrologic–Economic Framework

- Applies simultaneously mass-balance (inflow–evaporation–storage), capacity constraints, environmental-flow minima and service-level agreements (≥ 80 % industrial, ≥ 70 % agricultural).

Seasonal Insight

- Represents intra-annual variations in inflows and demands, identifying high-value months (April peak) and low-benefit times (September).

Penalty-Based Shortage Management

- Inserts economically weighted slack variables to measure and deter unserved demands in a transparent way.

Decision-Support Visualization

- Uses group bars, stack plots, heatmaps and storage-vs-capacity plots to report allocations, shortages, service levels and reservoir behavior in an easy-to-see manner.

Scalable & Transparent

- Constructed from standard LP code, the model is quickly re scalable to different sets of parameters, different scenarios or additional sub-basins.

Overall, the optimization framework consistently reconciles competing uses, optimizes basin-wide benefits, and provides transparent, data-driven advice for water-resource planning.

FINAL CODE:

```
clc; clear; close all;

%% Simplified Water Resource Optimization for Karnataka-Tamil Nadu Basin

% System Parameters
n_months    = 12;
months      = 1:n_months;
months_lbl  = {'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Oct','Nov','Dec'};

% Seasonal Agri values (crores per BCM)
agri_USD_K = [12,12,8,8,5,15,15,15,15,8,8,12] * 1e3 * 86;    % K harvest pattern
agri_USD_T = [13,14,14,12,8,5,5,8,12,15,15,15] * 1e3 * 86;    % TN harvest pattern

% Industrial and transfer profits
ind_USD      = [190e3,190e3] * 86;     % (K, TN)
transfer_USD = 200e3 * 86;
storage_USD  = [2e3,2e3] * 86;
penalty_agri = 500e3 * 86;
penalty_ind  = 100e3 * 86;

economic_params = struct( ...
    'agri_K', agri_USD_K, 'agri_T', agri_USD_T, ...
    'ind',    ind_USD,    'transfer', transfer_USD, ...
    'storage', storage_USD, 'penalty_agri', penalty_agri, 'penalty_ind', penalty_ind ...
);
region_weights = [0.6, 0.4];      % weights for (K, TN)
env_flow       = 0.05;            % BCM/month
sla            = struct('ind_min',0.8, 'agri_min',0.7);

% Household minimum releases (BCM/month)
hh_min_K = 0.12 * ones(1,n_months);
hh_min_T = 0.10 * ones(1,n_months);

% Reservoir parameters
reservoirs.K = init_reservoir_params('Karnataka', 3.244283, 2.094905);
reservoirs.T = init_reservoir_params('Tamil Nadu', 3.646771, 1.544823);

% Decision variables
var_names = {'K_ag','K_in','K_hh','T_ag','T_in','T_hh','R','S_K','S_T','sK','sT','sKi','sTi'};
offset = struct();
for i = 1:numel(var_names)
    offset.(var_names{i}) = (i-1)*n_months;
end
n_vars = numel(var_names)*n_months;

% Objective
f = create_objective(n_vars, offset, economic_params, region_weights, n_months);

% Constraints
[Aineq, bineq, Aeq, beq] = build_constraints(reservoirs, offset, n_months, sla);

% Bounds
```

```matlab
[lb, ub] = set_bounds(reservoirs, offset, n_months, n_vars, env_flow, sla, hh_min_K, hh_min_T);

% Solve
opts = optimoptions('linprog','Display','none');
[x, fval] = linprog(f, Aineq, bineq, Aeq, beq, lb, ub, opts);

% Results
res = process_results(x, offset, n_months);
fprintf('Total annual net benefit: ₹%.2f crore\n', fval/1e7);

%% plots (same as before) ...
% (Your bar, line, area, heatmap, sankey, etc.)
%%=== Visualization ===%%

% 1) Monthly Allocations & Transfer (grouped bar)
figure;
bar(months, [res.K_ag, res.K_hh, res.K_in, res.T_ag, res.T_hh, res.T_in, res.R], 'grouped');
legend('K Agri','K House','K Ind','T Agri','T House','T Ind','Transfer','Location','NorthWest');
xticks(months); xticklabels(months_lbl);
title('Monthly Allocations & Transfer'); ylabel('BCM'); grid on;

% 2) Storage vs Capacity: Karnataka
figure;
plot(months, res.S_K, 'b-o','LineWidth',1.5); hold on;
yline(reservoirs.K.Capacity, 'b--', 'K Capacity','LineWidth',1);
xticks(months); xticklabels(months_lbl);
xlabel('Month'); ylabel('Storage (BCM)');
title('Karnataka Reservoir Storage vs Capacity'); grid on;

% 3) Storage vs Capacity: Tamil Nadu
figure;
plot(months, res.S_T, 'r-s','LineWidth',1.5); hold on;
yline(reservoirs.T.Capacity, 'r--', 'T Capacity','LineWidth',1);
xticks(months); xticklabels(months_lbl);
xlabel('Month'); ylabel('Storage (BCM)');
title('Tamil Nadu Reservoir Storage vs Capacity'); grid on;

% 4) Stacked Area: Monthly Water Allocations & Transfer
figure;
area(1:12, [res.K_ag, res.K_in, res.K_hh, res.R, res.T_ag, res.T_in, res.T_hh]);
legend('K Agri','K Ind','K House','Transfer','T Agri','T Ind','T House','Location','EastOutside');
xticks(1:12); xticklabels(months_lbl);
title('Stacked Area: Monthly Water Allocations & Transfer'); ylabel('BCM'); grid on;

% 5) Monthly Shortages (stacked bar)
figure;
b = [res.sK, res.sKi, res.sT, res.sTi];
bar(1:12, b, 'stacked');
legend('Slack Ag K','Slack Ind K','Slack Ag T','Slack Ind T','Location','NorthEast');
xticks(1:12); xticklabels(months_lbl);
```

```matlab
title('Monthly Agricultural & Industrial Shortages'); ylabel('BCM'); grid on;

% 6) Heatmap of Service Levels (Allocation/Demand)
SL = zeros(12,4);
SL(:,1) = res.K_ag ./ reservoirs.K.DemandAgri';
SL(:,2) = res.K_in ./ reservoirs.K.DemandInd';
SL(:,3) = res.T_ag ./ reservoirs.T.DemandAgri';
SL(:,4) = res.T_in ./ reservoirs.T.DemandInd';
sector_lbl = {'K Agri','K Ind','T Agri','T Ind'};
figure;
heatmap(months_lbl, sector_lbl, SL', 'ColorbarVisible','on');
title('Heatmap: Service Levels (Allocation/Demand)'); xlabel('Month'); ylabel('Sector');


%%--- Line Diagrams: Sector Profits & Total Benefit ---%%

% Agricultural Profit
agri_vals_K = economic_params.agri_K(:);
agri_vals_T = economic_params.agri_T(:);
agri_profit_K = region_weights(1) * agri_vals_K .* res.K_ag;
agri_profit_T = region_weights(2) * agri_vals_T .* res.T_ag;

figure;
plot(months, agri_profit_K, '-go','LineWidth',1.5,'MarkerSize',8,'MarkerFaceColor','g'); hold on;
plot(months, agri_profit_T, '-mo','LineWidth',1.5,'MarkerSize',8,'MarkerFaceColor','m');
xticks(months); xticklabels(months_lbl);
xlabel('Month'); ylabel('Profit (₹)');
title('Monthly Agricultural Profit: Karnataka vs Tamil Nadu');
legend('Karnataka','Tamil Nadu','Location','NorthWest'); grid on;

% Industrial Profit
ind_profit_K = region_weights(1)*economic_params.ind(1) * res.K_in;
ind_profit_T = region_weights(2)*economic_params.ind(2) * res.T_in;
figure;
plot(months, ind_profit_K, '-co','LineWidth',1.5,'MarkerSize',8,'MarkerFaceColor','c'); hold on;
plot(months, ind_profit_T, '-bo','LineWidth',1.5,'MarkerSize',8,'MarkerFaceColor','b');
xticks(months); xticklabels(months_lbl);
xlabel('Month'); ylabel('Profit (₹)');
title('Monthly Industrial Profit: Karnataka vs Tamil Nadu');
legend('Karnataka','Tamil Nadu','Location','NorthWest'); grid on;

% Total Monthly Benefit
total_benefit = agri_profit_K + agri_profit_T + ind_profit_K + ind_profit_T
+ economic_params.transfer*res.R + region_weights(1)*economic_params.storage(1)*res.S_K
+ region_weights(2)*economic_params.storage(2)*res.S_T - economic_params.penalty_agri*(res.sK+res.sT)
- economic_params.penalty_ind*(res.sKi+res.sTi);
figure;
plot(months, total_benefit, '-ko','LineWidth',1.5,'MarkerSize',8,'MarkerFaceColor','k');
xticks(months); xticklabels(months_lbl);
xlabel('Month'); ylabel('Benefit (₹)');
title('Total Monthly Benefit'); grid on;
```

```matlab


%%--- Functions ---%%
function res = init_reservoir_params(name, cap, s0)
    res.Name        = name;
    res.Capacity    = cap;
    res.InitStorage = s0;
    switch name
      case 'Karnataka'
        res.Inflow     = [0.052161,0.043307,0.025151,0.031029,0.031029,0.657338,0.031029,2.817014,0.031029,1.901920,0.171738,0.161172];
        res.Evap       = [0.4768,0.2477,0.1306,0.3482,1.6144,2.1455,1.9850,2.8208,2.5196,2.8117,1.9204,1.0842];
        res.DemandAgri = [0.84942,1.41615,1.84035,1.84035,1.98252,1.84035,1.55781,1.27458,1.27458,0.99189,0.84942,0.84942];
        res.DemandInd  = repmat(0.0473,1,12);
      case 'Tamil Nadu'
        res.Inflow     = [0.064365,0.014808,0.012054,0.067341,0.067341,0.268025,0.067341,1.749602,0.067341,1.400768,0.411934,0.452935];
        res.Evap       = [0.1997,0.1170,0.0606,0.0809,0.7616,0.9879,0.7723,1.4767,0.9255,1.3932,0.9879,0.8317];
        res.DemandAgri = [0.93309,1.49742,2.06181,2.34654,2.06181,1.77903,1.21536,0.93309,0.93309,0.93309,0.93309,0.03078];
        res.DemandInd  = repmat(0.0933,1,12);
    end
end

function f = create_objective(nv, off, econ, w, nm)
    f = zeros(nv,1);
    for t=1:nm
        f(off.K_ag + t) = -w(1)*econ.agri_K(t);
        f(off.T_ag + t) = -w(2)*econ.agri_T(t);
    end
    f(off.K_in + (1:nm)) = -w(1)*econ.ind(1);
    f(off.T_in + (1:nm)) = -w(2)*econ.ind(2);
    f(off.K_hh + (1:nm)) = 0;
    f(off.T_hh + (1:nm)) = 0;
    f(off.R    + (1:nm)) = -econ.transfer;
    f(off.S_K  + (1:nm)) = -w(1)*econ.storage(1);
    f(off.S_T  + (1:nm)) = -w(2)*econ.storage(2);
    f(off.sK   + (1:nm)) =  econ.penalty_agri;
    f(off.sT   + (1:nm)) =  econ.penalty_agri;
    f(off.sKi  + (1:nm)) =  econ.penalty_ind;
    f(off.sTi  + (1:nm)) =  econ.penalty_ind;
end

function [Ai, bi, Ae, be] = build_constraints(res, off, nm, sla)
    nv = numel(fieldnames(off)) * nm;
    Ai=[]; bi=[]; Ae=[]; be=[];
    for m=1:nm
      %% Karnataka mass-balance
      eq = zeros(1,nv);
      idxS = off.S_K + m;
      if m>1, eq(off.S_K + m - 1) = -1; end
      eq(idxS) = 1;
      eq([off.K_ag+m, off.K_hh+m, off.K_in+m, off.R+m]) = -1;
      Ae = [Ae; eq];
```

```matlab
      be = [be; res.K.InitStorage*(m==1) + res.K.Inflow(m) - res.K.Evap(m)];

      %% Tamil Nadu mass-balance
      eq = zeros(1,nv);
      idxS = off.S_T + m;
      if m>1, eq(off.S_T + m -1) = -1; end
      eq(idxS) = 1;
      eq([off.T_ag+m, off.T_hh+m, off.T_in+m]) = -1;
      eq(off.R+m) = 1;
      Ae = [Ae; eq];
      be = [be; res.T.InitStorage*(m==1) + res.T.Inflow(m) - res.T.Evap(n) - 0.28317];

      %% Shortage = Demand for each sector (explicit)
      % K Agri
      eq = zeros(1,nv);
      eq(off.K_ag+m) = 1;  eq(off.sK+m) = 1;
      Ae = [Ae; eq];  be = [be; res.K.DemandAgri(m)];
      % T Agri
      eq = zeros(1,nv);
      eq(off.T_ag+m) = 1;  eq(off.sT+m) = 1;
      Ae = [Ae; eq];  be = [be; res.T.DemandAgri(m)];
      % K Ind
      eq = zeros(1,nv);
      eq(off.K_in+m) = 1; eq(off.sKi+m) = 1;
      Ae = [Ae; eq];  be = [be; res.K.DemandInd(m)];
      % T Ind
      eq = zeros(1,nv);
      eq(off.T_in+m) = 1; eq(off.sTi+m) = 1;
      Ae = [Ae; eq];  be = [be; res.T.DemandInd(m)];

      %% Service-level inequalities
      % K Ind
      ineq = zeros(1,nv);
      ineq(off.K_in+m) = -1; ineq(off.sKi+m) = -1;
      Ai = [Ai; ineq]; bi = [bi; -sla.ind_min*res.K.DemandInd(m)];
      % T Ind
      ineq = zeros(1,nv);
      ineq(off.T_in+m) = -1; ineq(off.sTi+m) = -1;
      Ai = [Ai; ineq]; bi = [bi; -sla.ind_min*res.T.DemandInd(m)];
      % K Agri
      ineq = zeros(1,nv);
      ineq(off.K_ag+m) = -1; ineq(off.sK+m) = -1;
      Ai = [Ai; ineq]; bi = [bi; -sla.agri_min*res.K.DemandAgri(m)];
      % T Agri
      ineq = zeros(1,nv);
      ineq(off.T_ag+m) = -1; ineq(off.sT+m) = -1;
      Ai = [Ai; ineq]; bi = [bi; -sla.agri_min*res.T.DemandAgri(m)];
    end
end

function [lb, ub] = set_bounds(res, off, nm, nv, env_flow, sla, hh_min_K, hh_min_T)
```

```matlab
    lb = zeros(nv,1);
    ub = inf(nv,1);
    for m = 1:nm
        ub(off.S_K+m)    = res.K.Capacity;
        ub(off.S_T+m)    = res.T.Capacity;
        ub(off.K_ag+m)   = res.K.DemandAgri(m);
        ub(off.T_ag+m)   = res.T.DemandAgri(m);
        ub(off.K_in+m)   = res.K.DemandInd(m);
        ub(off.T_in+m)   = res.T.DemandInd(m);
        lb(off.R+m)      = env_flow;
        lb(off.K_hh+m)   = hh_min_K(m);
        lb(off.T_hh+m)   = hh_min_T(m);
    end
end

function res = process_results(x, off, nm)
    idx = 1:nm;
    res.K_ag  = x(off.K_ag + idx);
    res.K_hh  = x(off.K_hh + idx);
    res.K_in  = x(off.K_in + idx);
    res.T_ag  = x(off.T_ag + idx);
    res.T_hh  = x(off.T_hh + idx);
    res.T_in  = x(off.T_in + idx);
    res.R     = x(off.R    + idx);
    res.S_K   = x(off.S_K  + idx);
    res.S_T   = x(off.S_T  + idx);
    res.sK    = x(off.sK   + idx);
    res.sT    = x(off.sT   + idx);
    res.sKi   = x(off.sKi  + idx);
    res.sTi   = x(off.sTi  + idx);
end
```

CODE FILE LINK: - CE718_project_code.m

DATASET FILE LINK: - Datasets