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CE718: WATER RESOURCES SYSTEMS ANALYSIS

COURSE PROJECT REPORT

Group Number 13

Optimizing Reservoir Operation: Ukai Reservoir

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1 Introduction

Water is a vital but limited resource facing growing pressure due to increasing **population** and **economic development**. Effective **water management** is necessary to balance the rising demands of **agriculture**, **industry**, **domestic use**, and the **environment**. The **Dublin Statement** recognizes water as an **economic good**, encouraging its efficient and equitable use. In India, reservoirs like **Ukai** are essential for multipurpose water allocation. With escalating sectoral competition, there is a need for scientifically informed and optimized reservoir operation strategies that support sustainable use and fair distribution.

2 Background

Conventional reservoir operations are based on **rule curves** and **simulation models**, which often lack responsiveness to varying conditions. **Optimization techniques** such as **Linear Programming (LP)**, **Dynamic Programming (DP)**, and **stochastic models** have emerged as tools for improving allocation efficiency. Legal, social, and institutional constraints also affect water distribution. Integrating **advanced computational methods** with hydrologic forecasting can enhance the ability to manage complex systems like the **Ukai Reservoir** under uncertainty.

3 Problem Statement

The **Ukai Reservoir** serves multiple competing needs—**irrigation**, **domestic supply**, and **industrial use**. Increasing demand, variability in inflows, and limited real-time adaptability of existing strategies result in suboptimal allocation. Reservoir operations must now accommodate **seasonal fluctuations**, maintain **storage levels**, and account for **non-market constraints** like legal or cultural considerations. Traditional approaches do not adequately balance conflicting objectives or allow flexible planning. This study proposes a solution through the development of a **Linear Programming-based optimization model**. The model aims to allocate water monthly across different sectors by incorporating constraints on **storage**, **release**, and **inflow variability**. The goal is to maximize overall utility while supporting **sustainable reservoir management** and equitable access across sectors.

4 Objectives

This study focuses on optimizing the monthly water release strategy for the **Ukai Reservoir**. The specific objectives are:

- To optimize monthly releases for **irrigation**, **domestic**, and **industrial** needs.
- To compare **actual** and **optimized** release schedules.
- To improve monthly reservoir **storage efficiency** while meeting sectoral demands.

5 Study Area Description

5.1 Geographical and Hydrological Features

The Ukai Dam, also known as **Vallabh Sagar**, is located in southern **Gujarat**, approximately 94 km from Surat and 29 km upstream of the Kakrapar weir. Constructed in 1971, it lies across the Tapti River and plays a crucial role in the hydrology of the region. The dam's catchment area spans approximately 62,255 km^2, situated between **longitudes 73°32'25"E to 78°36'30"E and latitudes 20°05'00"N to 22°52'30"N**. It supports a vast water spread area of about 52,000 hectares. In terms of capacity, it is comparable to the Bhakra Nangal Dam, highlighting its significance as one of India's major reservoirs.

5.2 Key Water Infrastructure

Among Gujarat's 541 dams, 21 are classified as large dams. However, only five—**Dharoi, Dantiwada, Kadana, Ukai, and Sardar Sarovar**—are considered major contributors to the state's water supply. The Ukai Dam stands out as Gujarat's second-largest reservoir and is regarded as a flagship project. It alone accounts for nearly 46% of the total storage capacity of all dams in Gujarat combined, with the rest contributing an average of only 0.1% each. This underscores its strategic importance in the state's water infrastructure.

5.3 Water Users and Demand Sectors

Ukai Dam serves multiple purposes, making it a multipurpose infrastructure project. Its primary uses include:

- **Irrigation:** Supporting agriculture in large command areas.
- **Power Generation:** Harnessing hydropower for regional energy needs.
- **Flood Control:** Moderating seasonal floods in the Tapti basin and surrounding districts.
- **Domestic and Industrial Water Supply:** Catering to the water needs of nearby urban and industrial zones, including Surat.

Its pivotal role makes it a backbone for water security in south Gujarat and a benchmark for evaluating integrated water resource systems in the region.

6 Network Diagram

The network diagram represents a schematic layout of the **Ukai Reservoir water resource system**, illustrating the interaction between key hydrological components and water demand nodes. It includes the **Ukai Reservoir**, **inflow sources**, and **evaporation losses**, and categorizes water users into **irrigation**, **domestic**, and **industrial** sectors.

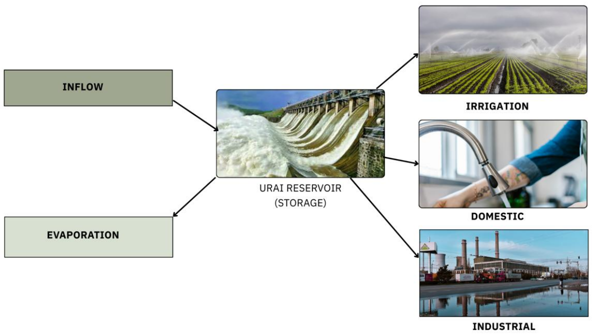

Figure 1: Network Diagram

7 Methodology

7.1 LP Model Formulation for Ukai Reservoir

Linear Programming (LP) is widely used in water resource management, particularly for optimizing reservoir operations. In this study, an LP model is developed to maximize water release from the Ukai Reservoir.

The formulation process includes the following steps:

1. **Objective Function:** Define the goal of the model—here, to maximize water release.
2. **Decision Variables:** Identify the key variables, such as the volume of water released in each time period.
3. **Objective Function Formulation:** Translate the objective into a mathematical expression suitable for LP.
4. **Constraints:** Include limitations like reservoir capacity, environmental regulations, and water demand.
5. **Mathematical Constraints:** Express these restrictions as linear equations or inequalities to guide the optimization.

7.2 Linear Programming Model (LP Model)

The goal is to maximize the total water release over 12 months for irrigation, domestic, and industrial purposes:

$$\text{Maximize } Z = \sum_{t=1}^{12} RI_t + \sum_{t=1}^{12} RID_t + \sum_{t=1}^{12} RIND_t$$

Where:

- Z = Total water released from the reservoir over a year
- RI_t = Water released for irrigation in month t
- RID_t = Water released for domestic use in month t
- $RIND_t$ = Water released for industrial use in month t
- t = Time period (months), where $t = 1, 2, \ldots, 12$

Subject to Constraints

1. **Irrigation Demand Constraint:**

$$ID_{min} \leq RI_t \leq ID_t$$

   - ID_t = Maximum irrigation demand in month t
   - ID_{min} = Minimum irrigation release required in month t

2. **Domestic Demand Constraint:**

$$DD_{min} \leq RID_t \leq DD_t$$

   - DD_t = Maximum domestic demand in month t
   - DD_{min} = Minimum domestic release required in month t

3. **Industrial Demand Constraint:**

$$INDD_{min} \leq RIND_t \leq INDD_t$$

   - $INDD_t$ = Maximum industrial demand in month t
   - $INDD_{min}$ = Minimum industrial release required in month t

4. **Storage Capacity Constraint:**

$$S_{min} \leq S_t \leq S_{max}$$

   - S_t = Reservoir storage at the start of month t
   - S_{max} = Maximum capacity of the reservoir
   - S_{min} = Dead storage level (minimum permissible storage)

5. **Reservoir Continuity Constraint:**

$$S_t + I_t - (RI_t + RID_t + RIND_t) - E_t = S_{t+1}$$

   - I_t = Inflow into the reservoir during month t
   - E_t = Evaporation loss during month t
   - S_{t+1} = Storage at the start of the next month

6. **Non-Negativity Constraint:**

$$RI_t, RID_t, RIND_t \geq 0$$

   All release values must be non-negative (cannot release negative water).

8 Data Collection and Assumptions

8.1 Data Conversion and Methodology

Collected data was processed and converted into a structured format suitable for LP model formulation in Python. Monthly release data from the Ukai reservoir—categorized into irrigation, domestic, and industrial uses—was extracted. Time is represented in months from January (1) to December (12). The minimum and maximum monthly release values for each category are used to define the model's constraints, and the processed data is summarized in tabular form.

8.2 Inflows and Stochastic Programming

To address the uncertainty in reservoir inflows due to variable rainfall, stochastic programming is applied using 21 years of historical inflow data. For this analysis, inflows at a 75% reliability level are used (refer to Figure 3), ensuring a conservative and dependable water availability scenario in the LP model.

8.3 Irrigation Water Release Analysis

The irrigation water release data is analyzed to determine the monthly maximum, minimum, and average volumes released over the past 21 years. These statistics, shown in Figure 2, serve as key constraints in the Python-based LP optimization model.

8.4 Domestic Water Release Analysis

Monthly domestic water releases are similarly analyzed using 21 years of historical data. The derived maximum, minimum, and average volumes, presented in Figure 2, are used to define the constraint boundaries for domestic use in the LP model.

8.5 Industrial Water Release Analysis

Industrial water releases are evaluated using the same historical dataset. Figure 2 includes the monthly maximum, minimum, and average values, which form the constraint limits for industrial usage in the model.

8.6 Evaporation Loss Analysis

Evaporation is a major source of water loss in reservoir systems. This study incorporates average monthly evaporation losses based on 21 years of records, as detailed in Figure 4. These values are factored into the LP model to account for non-usable water volume.

Month	Irrigation_Min	Domestic_Min	Industrial_Min	Irrigation_Max	Domestic_Max	Industrial_Max	Irrigation_Avg	Domestic_Avg	Industrial_Avg
Jan	117.6	1.99	7	1026.81	4.95	26.62	380.05	3.22	15.62
Feb	210.24	1.88	7.6	621.44	5.8	22	337.11	3.49	14.96
Mar	160.54	2.89	11.84	712.63	5.82	20.96	400.78	4.61	15.93
Apr	253.57	1.24	12.8	709.54	4.9	27	454.88	2.96	16.45
May	227.43	3.78	4	645.82	7.23	7	419.75	5.44	5.59
Jun	44.08	2.25	6	726.92	6.77	22.22	298.5	4.67	14.27
Jul	44.61	2	9	648.42	7.13	13.77	281.06	4.46	11.49
Aug	12.12	1.77	10.2	240.45	8.15	14.1	92.56	4.61	12.62
Sep	68.47	3.03	10	336.51	5.87	14.56	199.44	4.49	11.62
Oct	196.46	2.28	11.88	1226.91	4.37	13.18	611.62	3.5	13.8
Nov	73.43	1.98	12	908.14	5	17.16	375.92	3.32	13.89
Dec	148.76	1.76	4	982.73	4.13	19.19	357.18	2.99	14.55

Figure 2: Water releases for Domestic/Irrigation/Industrial purposes

Month	# 60% Dependable Inflow (MCM)	# 75% Dependable Inflow (MCM)	# 90% Dependable Inflow (MCM)
Jan	1.85	2.35	3.36
Feb	1.7	2.48	3.46
Mar	1.88	2.8	
Apr	1.42	1.5	2.37
May	2.5	3.5	4.8
Jun	360	740	1030
July	1500	4200	
Aug	2000	3400	6000
Sep	2800		
Oct	475	1200	
Nov	69	72	78
Dec	62	64	70

Figure 3: Dependable inflow

Month	# Min Evaporation (MCM)	# Max Evaporation (MCM)	# Avg Evaporation (MCM)
Jan	24.98	45.56	33.79
Feb	31.56	52.45	39.95
Mar	34.63	58.55	43.58
Apr	35.25	67.23	48.91
May	39.34	69.34	52.38
Jun	40.32	66.43	53.69
July	36.23	68.43	47.15
Aug	33.41	58.98	42.21
Sep	31.78	56.32	39.77
Oct	30.15	54.41	38.38
Nov	27.78	52.21	36.16
Dec	36.87	50.43	33.72

Figure 4: Water evaporation losses in MCM

Month	# Irrigation (MCM)	# Domestic (MCM)	# Industrial (MCM)	# Total (MCM)
Jan	1026.81	4.95	26.62	1058.38
Feb	520.92	1.88	7.6	530.4
Mar	160.54	2.89	11.84	175.27
Apr	253.57	1.24	12.8	267.61
May	227.43	3.78	4	235.21
Jun	146.38	2.25	6	154.63
July	648.42	7.13	13.77	669.32
Aug	240.45	8.15	14.1	262.7
Sep	336.51	5.87	14.56	356.94
Oct	1226.91	4.37	13.18	1244.46
Nov	73.43	1.98	12	87.41
Dec	148.76	1.76	4	154.52

Figure 5: Optimise result for water releases for irrigation purposes

Month	Storage (MCM)
S1	3159.62
S2	2070.25
S3	1502.4
S4	1284.85
S5	969.58
S6	684.39
S7	684.39
S8	1157.92
S9	3633.01
S10	4236.3
S11	3328.47
S12	3282.77

Figure 6: Optimize result for water storage

Month	Optimized Releases (MCM)	Actual Releases (MCM)
Jan	1058.38	1389.41
Feb	530.4	743.28
Mar	175.27	357.98
Apr	267.61	412.56
May	235.21	545.92
Jun	145.63	323.54
July	669.32	431.93
Aug	262.7	1269.47
Sep	356.94	1718.06
Oct	1244.46	918.23
Nov	87.41	346.51
Dec	154.52	321.23

Figure 7: Total monthly releases from Ukai comparison

9 Results and Discussion

A linear programming (LP) model has been developed using Python to optimize the monthly water releases from the Ukai Reservoir. The model incorporates all relevant physical and operational constraints. The analysis has been carried out using a 75% dependable inflow condition, which is commonly used in water resource planning under typical flow scenarios.

The model provides optimized monthly releases of water for irrigation, domestic use, and industrial use. These results have been presented using tables and graphs. The monthly irrigation releases are shown in a table and illustrated in a figure. Similarly, optimized monthly releases for domestic and industrial purposes are presented in respective tables and figures. The total monthly water releases, combining all three purposes, are also shown in a table. Additionally, a table and corresponding figure display the optimized monthly storage levels in the reservoir.

A comparison has been made between the optimized releases generated by the model and the actual observed releases during the same period. This comparison is shown in a figure. The results indicate that the observed releases are generally higher than the optimized values, suggesting potential for more efficient water management through model-based planning using the Python implementation.

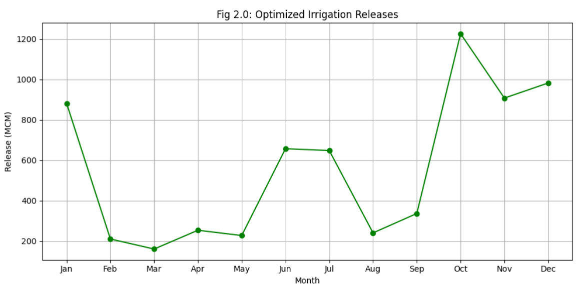

Figure 8: Optimised Irrigation Releases

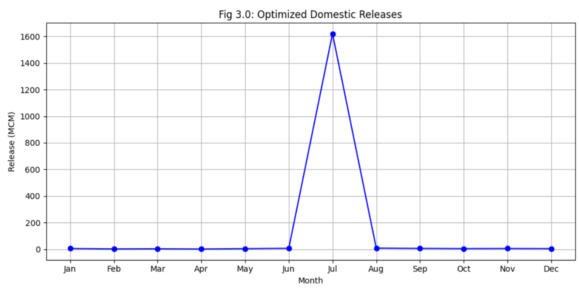

Figure 9: Optimised Domestic Releases

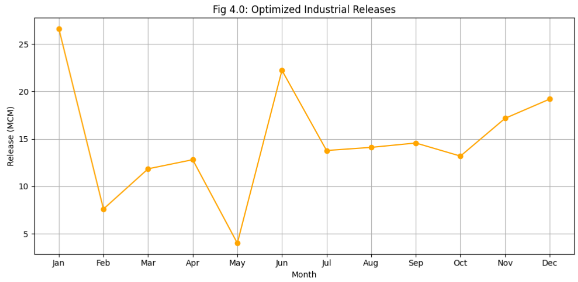

Figure 10: Optimised Industrial Releases

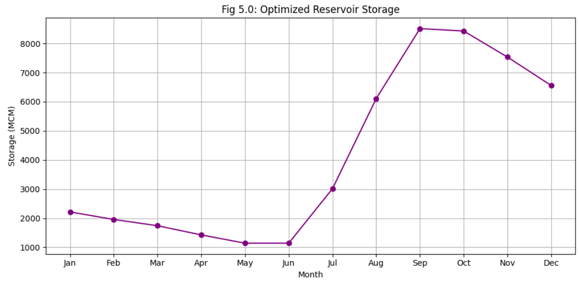

Figure 11: Optimised Reservoir Storage

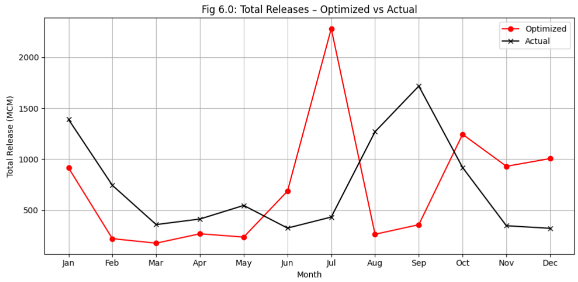

Figure 12: Total Releases — Optimised Vs Actual

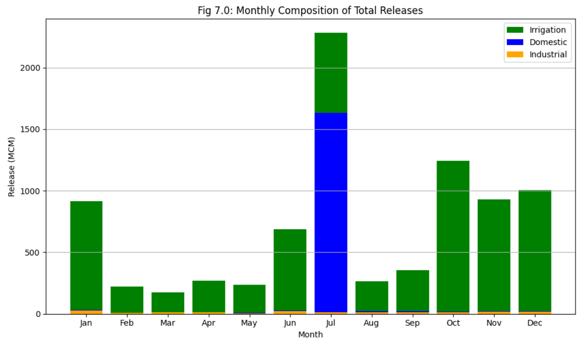

Figure 13: Monthly Composition of Total Releases

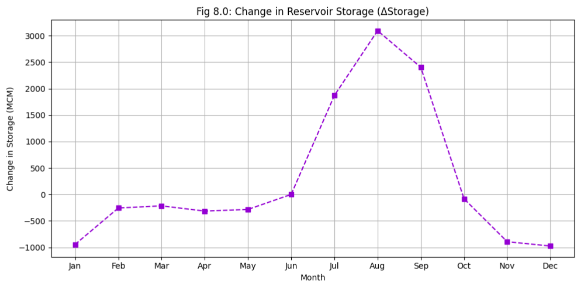

Figure 14: Change in Reservoir Storage (△ Storage)

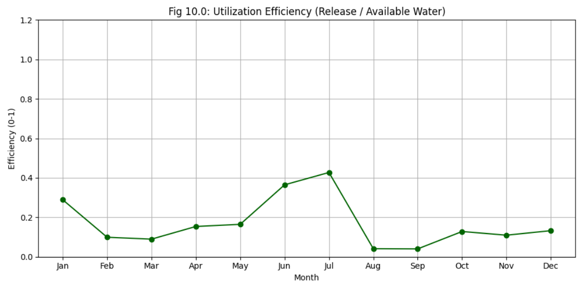

Figure 15: Utilisation Efficiency (Release/Available Water)

10 Conclusion

In this study, a Linear Programming (LP) model has been applied to optimize reservoir operations for water release planning. The model was developed specifically for the Ukai Reservoir with the objective of maximizing total water releases under given inflow conditions. The following key conclusions have been drawn from the analysis:

- Optimized monthly water releases for irrigation, domestic, and industrial purposes were obtained and compared with actual observed releases.
- The LP model was implemented using Python as the optimization tool to simulate water distribution and reservoir storage management.
- The total annual optimized water release from the reservoir was calculated to be approximately 5196.85 million cubic meters (mm^3) for all considered purposes.

11 References

1. Adib, A., Majd, A.R.M. (2009). Optimization of Reservoir Volume by Yield Model and Simulation of it by Dynamic Programming. *American-Eurasian J. Agric. Environ. Sci.*, 5(6), 796–803. IDOSI Publications. https://example.com/arash-adib-2009

2. Babel, M.S., Das Gupta, A., Nayak, D.K. (2005). A Model for Optimal Allocation of Water to Competing Demands. *Water Resources Management*, 19, 693–712.
`https://doi.org/10.1007/s11269-005-3281-7`
3. Bielsa, J., Duarte, R. (2001). An Economic Model for Water Allocation in North Eastern Spain. *Water Resource Development*, 17, 397–410.
`https://example.com/bielsa-duarte-2001`
4. Carriker, R.R. (1984). Issues in Water Allocation: Who Gets to Use How Much For What? *Farm Foundation*.
`https://example.com/carriker-1984`
5. Chatterjee, B., Howitt, R.E., Sexton, R.J. (1998). The Optimal Joint Provision of Water for Irrigation and Hydropower. *Journal of Environmental Economics and Management*, 36, 295–313.
`https://doi.org/10.1006/jeem.1998.1046`
6. Chaturvedi, M.C. (1982). Integrated Systems Planning for Water and Energy Resources of the Greater Ganga Basin. Gandhi Peace Foundation Workshop, New Delhi.
`https://example.com/chaturvedi-1982`
7. Debnath, D., Stoecker, A., Boyer, T., Sanders, L. (2009). Optimal Allocation of Reservoir Water: A Case Study of Lake Tenkiller. *Southern Agricultural Economic Association*.
`https://example.com/debnath-2009`
8. Frizzone, Z.A., et al. (1997). Linear Programming Model to Optimize the Water Resource Use in Irrigation Projects. *Sci. agric., Piracicaba*, 54, 136–148.
`https://example.com/frizzone-1997`
9. George, B., Malano, H.M., Davidson, B., Gaur, A. (2007). A Water Allocation Modeling Framework for the Musi Catchment, India. *Proceedings of the International Conference of Modeling Simulation*, Thailand.
`https://example.com/george-2007`
10. Georgiou, P.E., Papamichail, D.M. (2008). Optimization Model of an Irrigation Reservoir for Water Allocation and Crop Planning. *Irrig Sci*, 26, 487–504.
`https://doi.org/10.1007/s00271-008-0107-6`
11. Labadie, J.W., Lund, J. (2004). Discussion of "Optimal Operation of Multi-Reservoir Systems: State-of-the-Art Review." *Journal of Water Resources Planning and Management*, 130(2), 93–111.
`https://ascelibrary.org/doi/10.1061/(ASCE)0733-9496(2004)130:2(93)`
12. McKenzie, R.W. (2003). Examining Reservoir Managing Practices: The Optimal Provision of Water Resources Under Alternative Management Scenario. Ph.D. Dissertation, Oklahoma State University.
`https://example.com/mckenzie-2003`
13. Montazar, A., Riazi, H. (2008). Optimization of Water Allocation in Qazvin Irrigation Command Area. *Zeitschrift für Bewässerungswirtschaft*, 43(2), 129–143.
`https://example.com/montazar-2008`
14. Qubàa, R., El-Fade1, M., Darwish, M.R. (2002). Water Pricing for Multi-Sectoral Allocation: A Case Study. *Water Resource Development*, 18(4), 523–544.
`https://example.com/qubaa-2002`
15. Schilizzi, S., et al. (2011). Managing Multiple-Use Resources: Optimizing Reservoir Water Use for Irrigation and Fisheries. *55th AARES National Conference*, Melbourne.
`https://example.com/schilizzi-2011`
16. Schuman, H.A., Brass, C. (2003). An Optimization Model for Reservoir Systems. *IAHS Publ.*, 281.
`https://example.com/schuman-2003`
17. Sharma, K.M., et al. (2011). Assessment of Safe Reservoir Yield by Full Optimization Model. *International Journal of Water Resources and Environmental Engineering*, 3(10), 204–211.
`https://example.com/sharma-2011`
18. Shrestha, B.P., Duckstein, L., Stakhiv, E.Z. (1996). Fuzzy Rule-Based Modeling of Reservoir Operation. *Journal of Water Resource Planning and Management*, 122(4), 263–269.
`https://doi.org/10.1061/(ASCE)0733-9496(1996)122:4(263)`
19. Tsakiris, G., Spilotis, M. (2004). Fuzzy Linear Programming for Water Allocation under Uncertainty. *European Water*, 7/8, 25–37.
`https://example.com/tsakiris-2004`
20. Ward, F.A., Lynch, T.P. (1996). Integrated River Basin Optimization. *Water Resources Bulletin*, 32(6), 1127–1138.
`https://example.com/ward-lynch-1996`
21. Yeh, W.W.-G. (1985). Reservoir Management and Operations Models: A State-of-the-Art Review. *Water Resources Research*, 21(12), 1797–1818.
`https://doi.org/10.1029/WR021i012p01797`
22. Wurbs, R.A. (1991). Optimization of Multiple-Purpose Reservoir System Operations: A Review. *US Army Corps of Engineers, Research Document No. 34*.
`https://example.com/wurbs-1991`
23. Wurbs, R.A. (1997). Reservoir Water Management. *Water Resource Updates*, 106, Universities Council on Water Resources.
`https://example.com/wurbs-1997`

12 Appendix: Code Used

```
import pulp
import matplotlib.pyplot as plt

# Monthly index and labels
months = list(range(12))
months_labels = ["Jan", "Feb", "Mar", "Apr", "May", "Jun", "Jul", "Aug", "Sep", "Oct", "Nov", "Dec"]

# Data from PDF (in MCM)
inflow = [2.35, 2.48, 2.80, 1.50, 3.50, 740, 4200, 3400, 2800, 1200, 72, 64]
evap = [33.79, 39.95, 43.58, 48.91, 52.38, 53.69, 47.15, 42.21, 39.77, 38.38, 36.16, 33.72]

RI_min = [117.60, 210.24, 160.54, 253.57, 227.43, 44.08, 44.61, 12.12, 68.47, 196.46, 73.43, 148.76]
RI_max = [1026.81, 621.44, 712.63, 709.54, 645.82, 726.92, 648.42, 240.45, 336.51, 1226.91, 908.14,
```

```
    982.73]
RID_min = [1.99, 1.88, 2.89, 1.24, 3.78, 2.25, 2, 1.77, 3.03, 2.28, 1.98, 1.76]
RID_max = [4.95, 5.80, 5.82, 4.90, 7.23, 6.77, 7.13, 8.15, 5.87, 4.37, 5, 4.13]
RIND_min = [7, 7.6, 11.84, 12.8, 4, 6, 9, 10.2, 10, 11.88, 12, 4]
RIND_max = [26.62, 22, 20.96, 27, 7, 22.22, 13.77, 14.1, 14.56, 13.18, 17.16, 19.19]

# Storage data from PDF
Smin, Smax = 1142, 8511
S0 = 3159.62

# Actual release values from PDF Table 8.0 (for comparison plot)
actual_total = [1389.41, 743.28, 357.98, 412.56, 545.92, 323.54, 431.93, 1269.47, 1718.06, 918.23,
    346.51, 321.23]

# LP Model
model = pulp.LpProblem("Ukai_Reservoir_Optimization", pulp.LpMaximize)

RI = pulp.LpVariable.dicts("RI", months, lowBound=0)
RID = pulp.LpVariable.dicts("RID", months, lowBound=0)
RIND = pulp.LpVariable.dicts("RIND", months, lowBound=0)
S = pulp.LpVariable.dicts("S", range(13), lowBound=Smin, upBound=Smax)

# Initial storage
model += S[0] == S0

# Objective: Maximize total releases
model += pulp.lpSum([RI[t] + RID[t] + RIND[t] for t in months]), "Total_Releases"

# Add constraints
for t in months:
    model += RI[t] >= RI_min[t]
    model += RI[t] <= RI_max[t]
    model += RID[t] >= RID_min[t]
    model += RID[t] <= RID_max[t]
    model += RIND[t] >= RIND_min[t]
    model += RIND[t] <= RIND_max[t]
    model += S[t + 1] == S[t] + inflow[t] - (RI[t] + RID[t] + RIND[t]) - evap[t]

# Solve
model.solve()

# Extract results
irrigation = [RI[t].varValue for t in months]
domestic = [RID[t].varValue for t in months]
industrial = [RIND[t].varValue for t in months]
total = [irrigation[t] + domestic[t] + industrial[t] for t in months]
storage = [S[t + 1].varValue for t in months]


# 1. Irrigation
plt.figure(figsize=(10, 5))
plt.plot(months_labels, irrigation, marker='o', color='green')
plt.title("Optimized Irrigation Releases")
plt.xlabel("Month")
plt.ylabel("Release (MCM)")
plt.grid(True)
plt.tight_layout()
plt.show()

# 2. Domestic
plt.figure(figsize=(10, 5))
plt.plot(months_labels, domestic, marker='o', color='blue')
plt.title("Optimized Domestic Releases")
plt.xlabel("Month")
plt.ylabel("Release (MCM)")
plt.grid(True)
plt.tight_layout()
plt.show()

# 3. Industrial
plt.figure(figsize=(10, 5))
plt.plot(months_labels, industrial, marker='o', color='orange')
plt.title("Optimized Industrial Releases")
plt.xlabel("Month")
plt.ylabel("Release (MCM)")
plt.grid(True)
plt.tight_layout()
plt.show()

```

```python
# 4. Storage
plt.figure(figsize=(10, 5))
plt.plot(months_labels, storage, marker='o', color='purple')
plt.title("Optimized Reservoir Storage")
plt.xlabel("Month")
plt.ylabel("Storage (MCM)")
plt.grid(True)
plt.tight_layout()
plt.show()

# 5. Total Optimized vs Actual
plt.figure(figsize=(10, 5))
plt.plot(months_labels, total, marker='o', label="Optimized", color='red')
plt.plot(months_labels, actual_total, marker='x', label="Actual", color='black')
plt.title("Total Releases     Optimized vs Actual")
plt.xlabel("Month")
plt.ylabel("Total Release (MCM)")
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.show()

plt.figure(figsize=(10, 6))
plt.bar(months_labels, irrigation, label='Irrigation', color='green', bottom=[domestic[i] +
    industrial[i] for i in months])
plt.bar(months_labels, domestic, label='Domestic', color='blue', bottom=industrial)
plt.bar(months_labels, industrial, label='Industrial', color='orange')
plt.title("Monthly Composition of Total Releases")
plt.xlabel("Month")
plt.ylabel("Release (MCM)")
plt.legend()
plt.tight_layout()
plt.grid(True, axis='y')
plt.show()

storage_change = [storage[i] - S[i].varValue for i in months]  #  Storage  = S[t+1] - S[t]

plt.figure(figsize=(10, 5))
plt.plot(months_labels, storage_change, marker='s', linestyle='--', color='darkviolet')
plt.title("Fig 8.0: Change in Reservoir Storage ( Storage )")
plt.xlabel("Month")
plt.ylabel("Change in Storage (MCM)")
plt.grid(True)
plt.tight_layout()
plt.show()

plt.figure(figsize=(10, 5))
plt.plot(months_labels, efficiency, marker='o', linestyle='-', color='darkgreen')
plt.title("Fig 10.0: Utilization Efficiency (Release / Available Water)")
plt.xlabel("Month")
plt.ylabel("Efficiency (0-1)")
plt.ylim(0, 1.2)
plt.grid(True)
plt.tight_layout()
plt.show()
```

Listing 1: Ukai Reservoir Optimization using Linear Programming