INDIAN INSTITUTE OF SCIENCE

Water Resources Systems:

Modeling Techniques and Analysis

Lecture - 40

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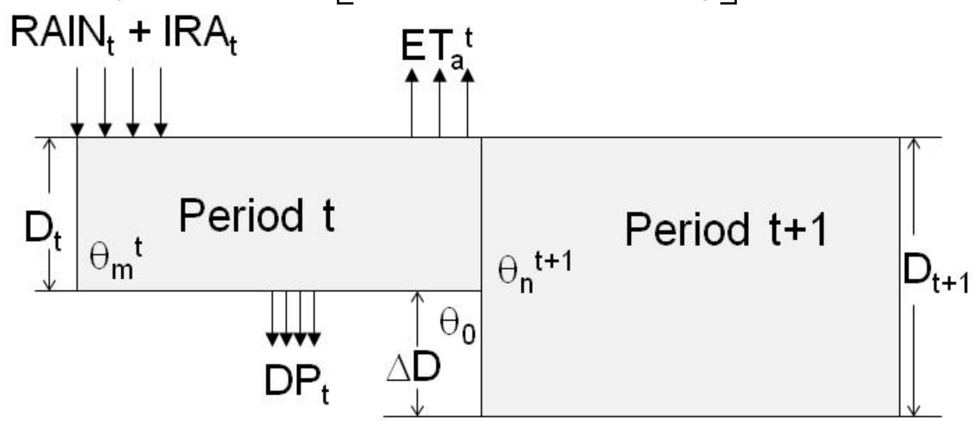
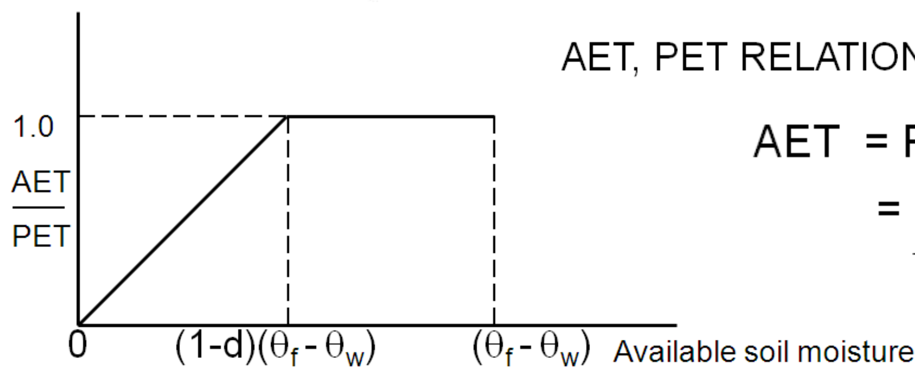
Summary of the previous lecture

Crop yield optimization:

$$\left(\frac{y}{y_m}\right)_c = \prod_{s=1}^{NS}\left[1 - ky_s^c\left(1 - \frac{ET_a^c}{ET_{max}^c}\right)_s\right] \qquad \left[\frac{y}{y_m}\right] = 1 - \sum_{g=1}^{N_g}\left[Ky_g\left(1 - \frac{AET}{PET}\right)_g\right]$$



$$\theta_n^{t+1} D_{t+1} = \theta_m^t\ D_t + RAIN_t + IRA_t - Et_a^t - DP_t + \theta_0\ \Delta D$$



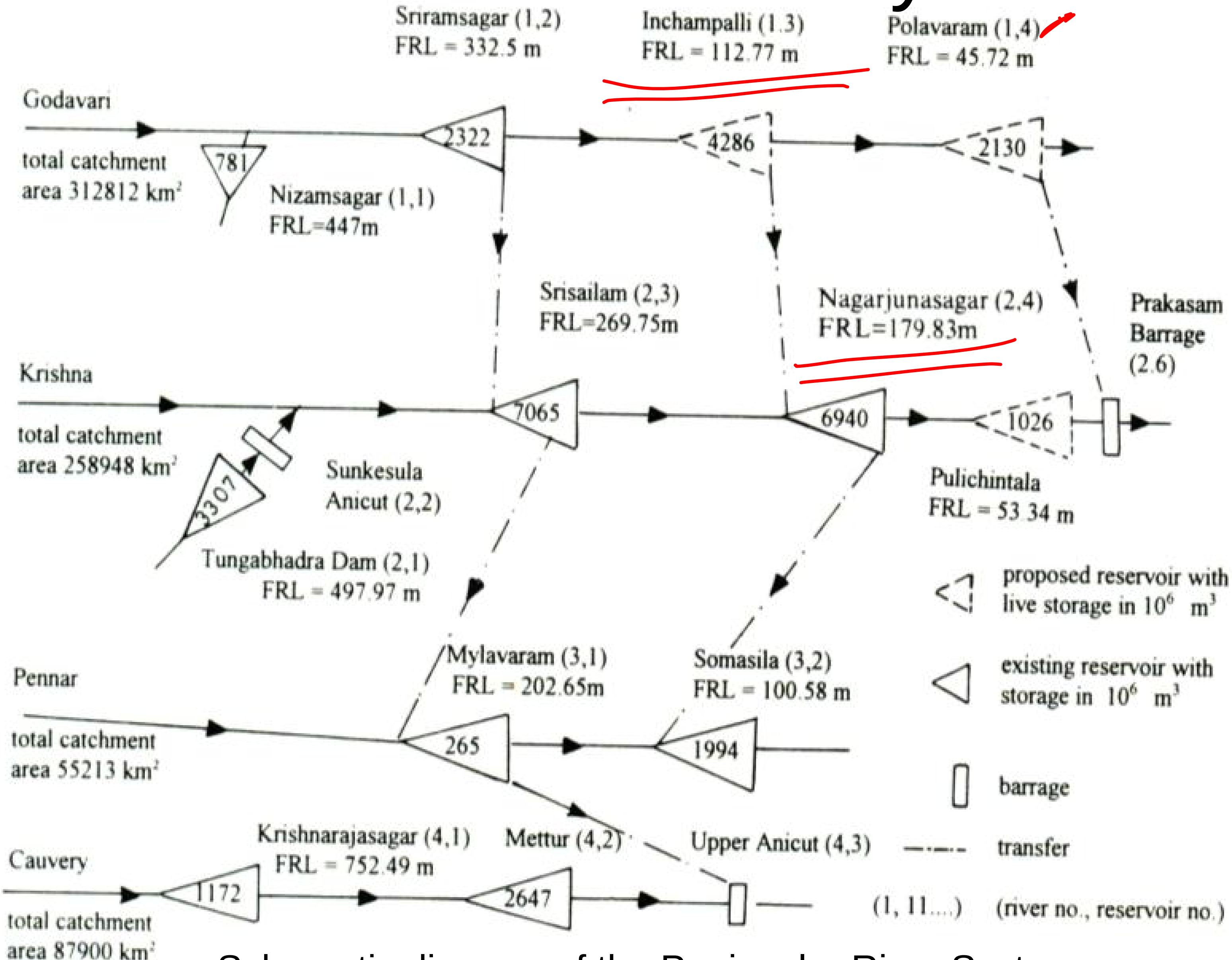
AET, PET RELATION

$$AET = PET \qquad \text{if } \theta_{avail} \geq (1\text{-}d)(\theta_f - \theta_w)$$

$$= \frac{\theta_{avail}\ PET}{(1\text{-}d)(\theta_f - \theta_w)} \qquad \text{Otherwise}$$

INTER-BASIN TRANSFER SYSTEMS

Inter-basin Transfer Systems



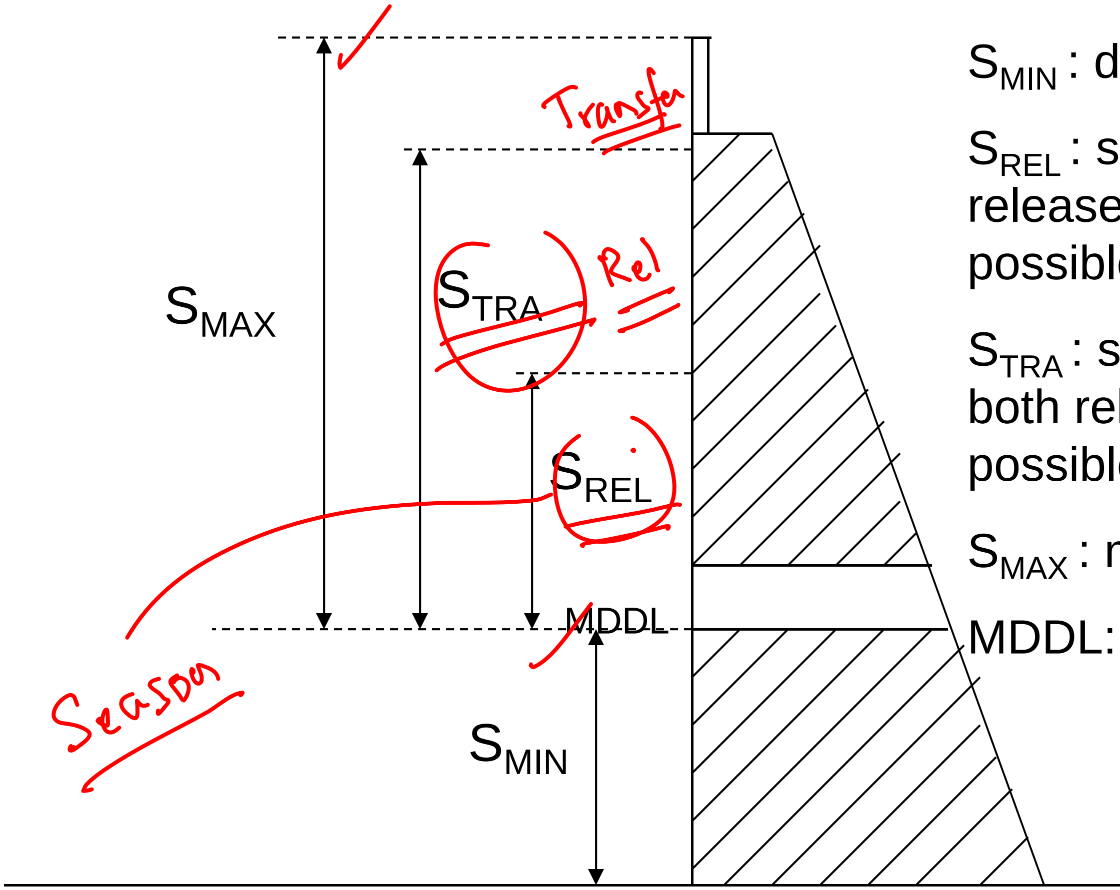
Schematic diagram of the Peninsular River System

Inter-basin Transfer Systems

Salient features of the reservoirs of the system

Reservoir (status*)	Location	Catchment area ($\times 10^3$ km^2)	Command area ($\times 10^4$ ha)	Power generated (MW)	Live storage (Mm^3)	Dead storage (Mm^3)	Period of inflow record
NZS (E)	76° 15' E 18° 10' N	21.7	11.13	15	780	60	1944-86
SRSP (E)	78° 30' E 18° 55' N	40.5	67.14	36	2320	850	1963-83
IC (P)	80° 25' E 18° 37' N	42.7	63.58	975	4286	6089	1950-75
POL (P)	81° 46' E 17° 13' N	37.6	29.14	---	2130	3381	1966-86
TB (E)	76° 18' E 15° 16' N	28.8	34.80	117	3307	457	1951-85
SA (E)	77° 45' E 15° 48' N	36.5	11.30	---	---	---	1966-87
SS (E)	78° 54' E 16° 05' N	NA	NA	770	7065	3049	1964-86
NS (E)	79° 36' E 16° 45' N	10.0	13.36	110	6940	4610	---
PC (P)	80° 03' E 16° 46' N	19.5	NA	---	1026	270	1945-81
PB (E)	80° 55' E 16° 35' N	16.6	48.56	---	---	---	1945-81
MYL (E)	78° 20' E 14° 51' N	19.2	1.95	---	266	17	1969-86
SMS (E)	79° 18' E 14° 29' N	29.4	16.39	---	1994	214	1929-82
KRS (E)	76° 31' E 12° 25' N	10.6	11.36	---	1172	125	1934-86
MET (E)	77° 55' E 11° 55' N	NA	12.14	200	2647	553	1966-87
UA (E)	78° 50' E 10° 50' N	NA	44.52	---	---	---	1966-87

Inter-basin Transfer Systems



S_{MIN} : dead storage capacity

S_{REL} : storage capacity above which release to downstream reservoirs is possible; no transfer

S_{TRA} : storage capacity above which both release and transfer are possible

S_{MAX} : maximum live storage capacity

MDDL: minimum draw down level

Ref: Vijay Kumar, V., Rao, B. V. and Mujumdar, P. P. (1996), Optimal Operation of MultibasinReservoir System, *Sadhana,* Indian Academy of Sciences, 21(4), pp. 487-502.

Inter-basin Transfer Systems

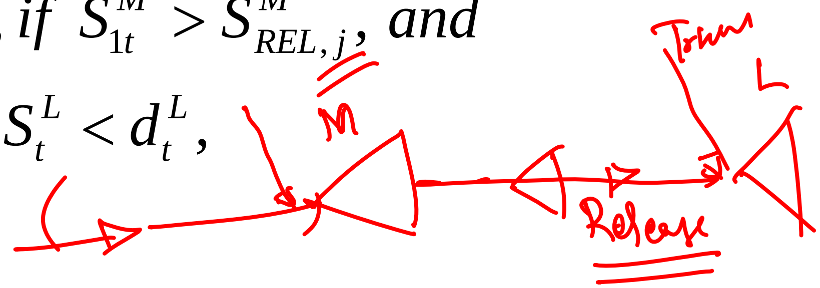
Release and transfer policies:

- Release $R_t^{M,L}$ from reservoir M to a downstream reservoir L, if exists, is given by

for the same basin.

$$R_t^{M,L} = MIN \begin{cases} S_{1t}^{M} - S_{REL,j}^{M}, \text{ if } S_{1t}^{M} > S_{REL,j}^{M}, \text{ and} \\ d_t^{L} - S_t^{L}, \text{ if } S_t^{L} < d_t^{L}, \end{cases}$$

$$= 0 \quad otherwise$$



S_{1t}^{M} : storage at reservoir M during period t after accounting for its own demand d_t^M , releases and transfers committed to the reservoir M from other reservoirs and release commitments made from the reservoir M to other reservoirs downstream of M

Inter-basin Transfer Systems

S_t^L : storage at the reservoir L after accounting for all transfers and releases from other reservoirs downstream of M, committed to it during the period and

$S_{REL,j}^M$: releasable storage for the reservoir M in season j to which the period t belongs.

d_t^L : water demand at reservoir L in period t

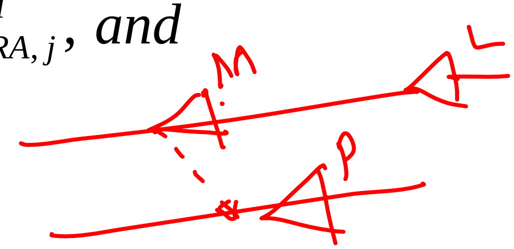
j : Season

Inter-basin Transfer Systems

- The amount of water transferred, $T_t^{M,P}$, from reservoir M of a basin to reservoir P of another basin in period t, when a transfer link exists, is given by

$$T_t^{M,P} = MIN \begin{cases} S_{2t}^{M} - S_{TRA,j}^{M}, \; if \;\; S_{2t}^{M} > S_{TRA,j}^{M}, \; and \\ d_t^P - S_t^P, \; if \;\; S_t^P < d_t^P, \end{cases}$$

$$= \quad 0 \quad otherwise$$



S_{2t}^{M} : storage available at reservoir M after accounting for the diversion and release,

$S_{TRA,j}^{M}$: transferable storage in reservoir M for the season j to which the period t belongs,

Inter-basin Transfer Systems

S_t^P : storage at the reservoir P after accounting for diversion, release and transfers committed to it for the period (by other reservoirs during the computations prior to those of reservoir M) and

d_t^P : water demand at reservoir P in period t.

- Two parameters, $INCR1$ for the monsoon season and $INCR2$ for the non-monsoon, are introduced as multiplying factors to the irrigation demands in the corresponding periods

Inter-basin Transfer Systems

Prominent transfers for 50-year simulation analysis

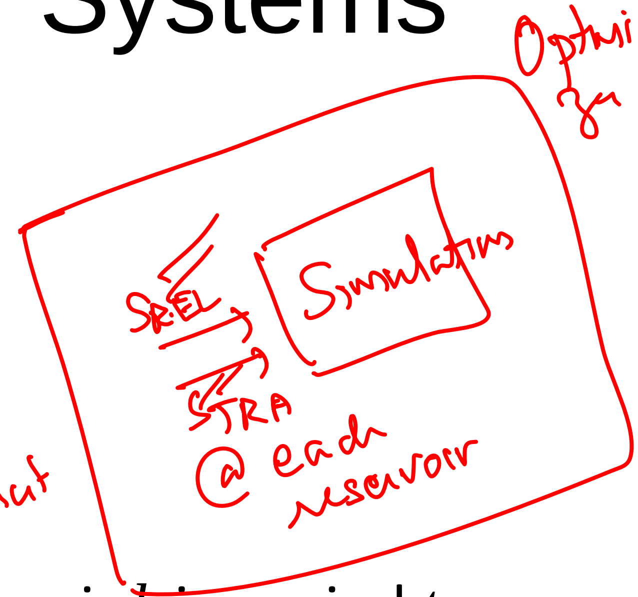
Month	From / to	Inchampally NS	Inchampally PC	Inchampally PB	Polavaram PB	Polavaram MYL	Srisailam SMS	Srisailam UA
Jun		---	257(4)	635(5)	5302(18)	223(15)	48(2)	18259(30)
Jul		4216(14)	13204(29)	580(3)	17941(29)	1951(41)	1967(13)	102362(49)
Aug		39495(27)	3470(10)	432(1)	13510(22)	1886(44)	3973(13)	81759(46)
Sep		13110(14)	3626(12)	1126(3)	25430(43)	1026(23)	1608(7)	37612(44)
Oct		---	937(3)	4296(10)	19605(35)	585(15)	1079(6)	---
Nov		---	210(3)	5886(20)	9421(27)	511(13)	405(3)	---
Dec		---	702(6)	2644(18)	2010(13)	490(14)	917(6)	---
Jan		---	---	---	600(8)	702(18)	732(7)	11842(43)
Feb		---	---	---	544(8)	578(19)	1098(9)	28686(42)
Mar		---	---	---	2293(19)	661(18)	768(7)	34481(38)
Apr		---	---	---	345(2)	510(15)	1188(8)	2594(31)
May		---	---	---	34(2)	340(11)	226(6)	---

Units: million cubic meters; figures in brackets indicate the number of times the transfer has taken place in a 50-year period

Inter-basin Transfer Systems

- Optimization model

$$Max. \sum_k \sum_t \alpha U_t^k - \beta D_t^k$$



U_t^k : amount of water utilized from reservoir k in period t,

D_t^k : deficit in reservoir k in period t,

α represents the economic value of the water actually utilized.

β represents the penalty (i.e., loss) associated with not meeting the demands

Inter-basin Transfer Systems

subject to

i) Diversion policy,

$$DIV_t^k = d_t^k \quad if, S_{it}^k + I_t^k > d_t^k$$
$$= S_{it}^k + I_t^k \quad otherwise$$

d_t^k : water demand at reservoir k in period t,

I_t^k : natural inflow to reservoir k in period t,

S_{it}^k : storage at the beginning of period t in reservoir k

ii) Release policy,

iii) Transfer policy,

Inter-basin Transfer Systems

iv) Definition constraints:

(a) $$D_t^k = d_t^k - U_t^k, \quad if \;\; positive$$
$$= 0 \qquad\qquad otherwise$$

(b) $$U_t^k = DIV_t^k + R_t^k + T_t^k$$

(c) $$d_t^k = INCR1^k (DEM_t^k), \quad \forall t \in monsoon \;\; season$$
$$= INCR2^k (DEM_t^k), \quad \forall t \in nonmonsoon \;\; season$$

v) Storage continuity, physical constraints and non-negativity of the variables; and

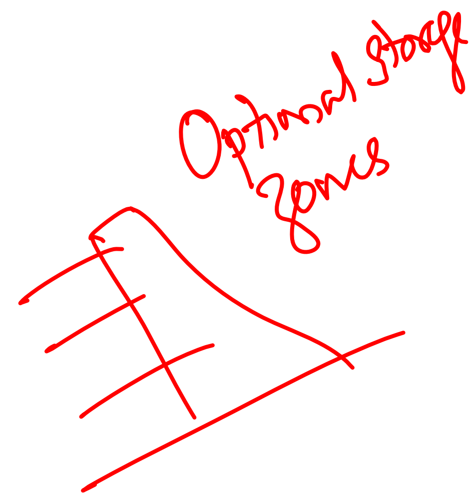
vi) Constraints due to priorities discussed in the simulation model.

Inter-basin Transfer Systems

Summary results of the optimization

Reservoir	$S_{REL,1}$ (Mm^3)	$S_{REL,2}$ (Mm^3)	$S_{TRA,1}$ (Mm^3)	$S_{TRA,2}$ (Mm^3)
(1,3)	1588.34	2793.47	2373.59	3873.01
(1,4)*	---	---	162.91	1232.78
(2,3)	1134.35	189.32	1521.93	417.15
(2,4)	895.74	1525.69	685.60	417.67

*There is no reservoir downstream of (1,4). Release not possible



Inter-basin Transfer Systems

Performance indices for the system:

- Failure index (F) : Ratio of the sum of all the failures to the total number of periods.
- Reliability (ρ) : $1 - F$
- Resiliency (γ) : Ratio of the number of transitions from failure state to a satisfactory state and the total number of failures
- Vulnerability (υ) : ratio of largest deficit during period of operation to the corresponding demand at the reservoir.
- Deficit ratio (δ) : ratio of the total deficit to the total demand.

Inter-basin Transfer Systems

Summary of the yearly performance indices for the system

Reliability (ρ)	0.946
Resiliency (γ)	0.680
Vulnerability (ν)	0.474
Deficit ratio (δ)	0.014

Inter-basin Transfer Systems

Monthly performance indices of the system

Index	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
ρ	0.903	0.907	0.986	0.992	0.983	0.977	0.960	0.946	0.930	0.911	0.859	0.869
γ	0.711	0.898	0.946	0.965	0.950	0.915	0.843	0.819	0.818	0.807	0.708	0.698
ν	0.663	0.287	0.632	0.632	0.632	0.441	0.397	0.595	0.731	0.762	0.755	0.561
δ	0.034	0.006	0.005	0.003	0.006	0.006	0.011	0.016	0.023	0.031	0.049	0.037

Yearly performance indices of the reservoirs

INDEX	NZS	SRSP	IC	POL	TB	SA	SS	NS	PC	PB	MYL	SMS	KRS	MET	UA
ρ	0.865	0.830	0.936	0.948	0.933	0.885	0.985	0.979	0.971	0.960	0.961	0.982	0.988	0.997	0.953
γ	0.688	0.664	0.755	0.839	0.752	0.696	0.902	0.974	0.716	0.661	0.772	0.811	0.822	1.000	0.666
ν	0.850	0.829	0.507	0.472	0.373	0.309	0.226	0.442	0.609	0.737	0.817	0.456	0.140	0.258	0.752
δ	0.051	0.059	0.019	0.014	0.017	0.029	0.004	0.006	0.008	0.012	0.014	0.005	0.003	0.001	0.014

Additional reference & Web courses

- Multicriterion Analysis in Engineering and Management by K. Srinivasa Raju and D. Nagesh Kumar, PHI Learning Pvt. Ltd., New Delhi, India, ISBN 978-81-203-3976-7, 2010

- NPTEL web courses

Prof. Nagesh Kumar

Water Resources Systems

http://www.nptel.iitm.ac.in/courses/105108081/

Optimization Methods

http://www.nptel.iitm.ac.in/courses/Webcourse-contents/IISc-BANG/OPTIMIZATION%20METHODS/New_index1.html

Advanced topics

- Genetic algorithms; Particle Swarm Optimization (PSO), Ant Colony Optimization (ASO)
- Artificial neural networks; Support Vector Machines