Integrated water resources management in large river basins based on simulation modeling and optimization methods

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Contents

1. Methods for constructing the best release rules that ensure the safe operation of facilities and the sustainable functioning of water management systems will be considered.
2. The construction of optimal compromise Release rules is based on the methods of multi-criteria analysis and the theory of trade-offs and should take into account the often conflicting requirements of water users.
3. To assess the quality of Release rules, statistical reliability criteria are used, which are formed as a result of performing water management calculations for long-term hydrological series of observed inflow.

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INTRODUCTION AND OBJECTIVES

1. Not to allow levels in reservoirs forced above the Flood control level until the capacity of the spillways is completely exhausted;
2. When carrying out different activities, maintain the limiting levels of water filling in reservoirs.
3. To prevent releases into the downstream reservoir, leading to damage from flooding of developed floodplain lands.
4. Ensure energy release in volumes determined by the rules;
5. Meet the requirements of water users: energy, navigation, municipal engineering, ecology, agriculture, and fisheries and others - in the amounts determined by the rules;
6. Maintain fishery releases during the spawning period, while preventing even short-term drops in reservoirs water levels;
7. Maintain agricultural releases during the growing season (April-September);
8. Provide water users with consistent reliability.

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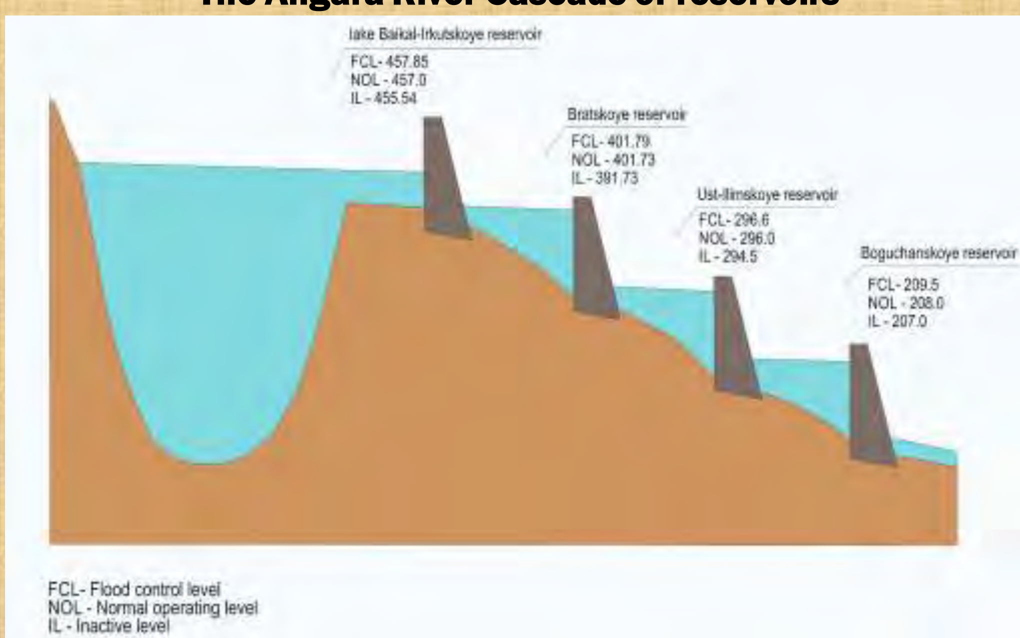
The Angara River Cascade of reservoirs



Baikal: the total volume - 23600 cubic km, depth - 1642 m, average annual inflow - 60 cubic кm

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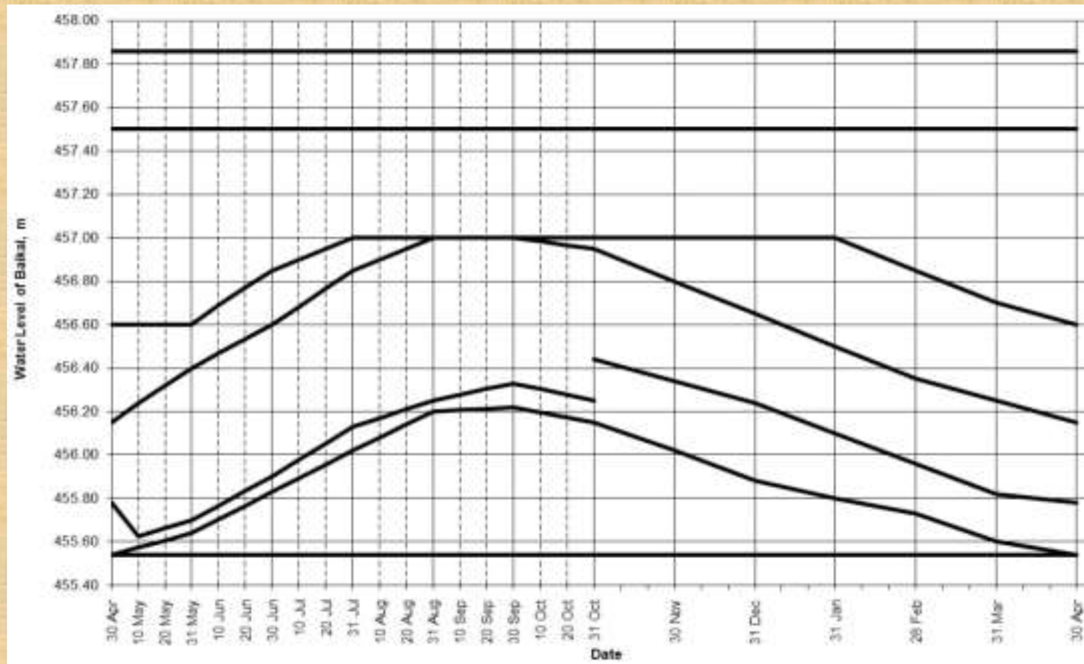
Dispatch schedule of “Lake Baikal – Irkutsk Reservoir” (release curves)



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Dispatch schedule of “Lake Baikal – Irkutsk Reservoir” (table)

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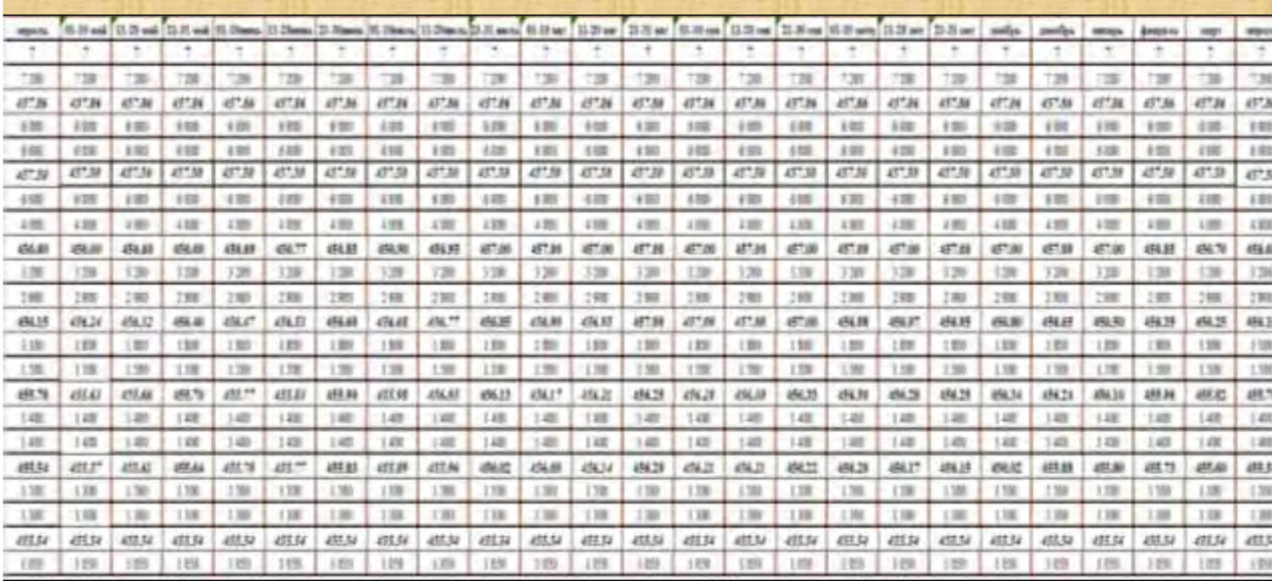

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Fragments of the Dispatcher schedules, Coordinate Table and long-term series of inflow to Lake Baikal

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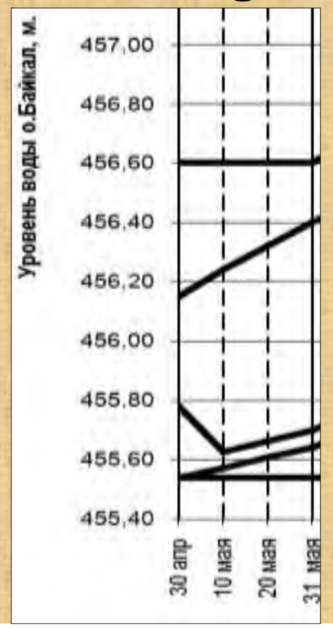

апрель	01-10 май	11-20 май
7	7	7
7 200	7 200	7 200
457.86	*457.86*	*457.86*
6 000	6 000	6 000
6 000	6 000	6 000
457.50	*457.50*	*457.50*
6 000	6 000	6 000
4 000	4 000	4 000
456.60	**456.60**	**456.60**
3 200	3 200	3 200
2 900	2 900	2 900
456.15	*456.24*	*456.32*
3 100	1 800	1 800
1 500	1 500	1 500
455.78	*455.63*	*455.66*
1 400	1 400	1 400
1 400	1 400	1 400
455.54	*455.57*	*455.61*
1 500	1 300	1 500

Intervals	V 1-10	V 11-20	V 21-31	VI 1-10
Years	01.05	11.05	21.05	01.06
2016-2017	2 123	2 123	2 123	2 990
2015-2016	1 705	2 903	1 596	3 918
2014-2015	2 230	2 161	2 671	3 621
2013-2014	2 101	3 562	3 323	3 705
2012-2013	1 770	4 034	1 307	7 165
2011-2012	2 462	3 173	1 708	3 375
2010-2011	1 712	2 892	1 049	5 087
2009-2010	2 787	2 642	3 032	3 918
2008-2009	1 772	2 178	2 307	2 981
2007-2008	2 150	2 489	3 246	4 539
2006-2007	2 428	2 621	3 235	5 327
2005-2006	1 880	2 237	1 304	5 159
2004-2005	3 132	2 798	4 690	4 207
2003-2004	1 101	1 657	3 548	2 800
2002-2003	2 673	3 874	2 037	5 732
2001-2002	2 784	3 796	3 001	5 627
2000-2001	2 280	5 529	3 568	8 963
1999-2000	2 935	3 787	4 096	3 671
1998-1999	1 139	3 979	2 343	2 989
1997-1998	2 303	2 246	4 218	4 130
1996-1997	2 052	2 782	1 964	4 604
1995-1996	1 775	2 961	4 314	5 048
1994-1995	2 175	2 553	2 108	2 829
1993-1994	3 440	1 690	2 132	5 655
1992-1993	2 644	3 493	5 633	4 388
1991-1992	1 879	3 070	5 242	3 811
1990-1991	1 350	2 020	1 535	2 624
1989-1990	1 680	2 414	1 726	3 353
1988-1989	1 090	2 253	1 316	6 639
1987-1988	2 127	2 131	1 271	4 166
1986-1987	3 281	3 147	1 899	4 962
1985-1986	2 560	2 652	4 633	6 258

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Principles of reservoir operation mode control (direct and reverse)

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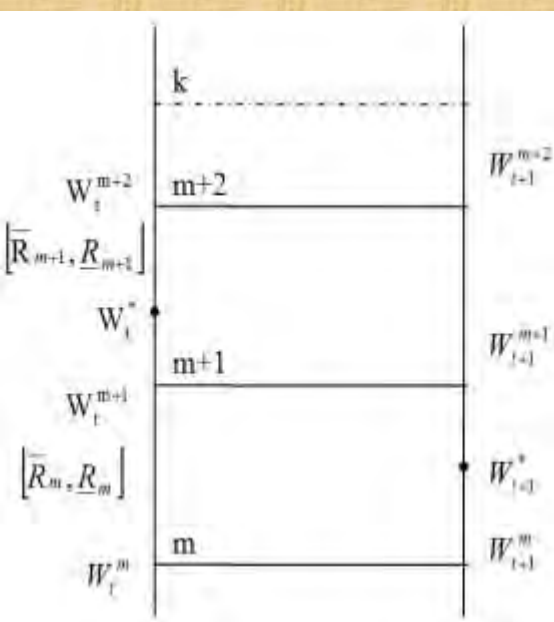

1. The water level at the dam at the end of the estimated time period is determined by the level at the beginning of the period, the predicted inflow and the range of acceptable releases, for the zone in which the level was located at the beginning of the period.

2. The water level at the dam at the end of the estimated time period is determined by the level at the beginning of the period, the predicted inflow and the range of allowable releases, for the zone in which the level will be at the end of the period.

Balance equation: $W^*_{t+1} = W^*_t + P_{t+1} - R_{t+1}$ where W^*_t , W^*_{t+1} are initial and final reservoir volumes, P_{t+1} inflow, R_{t+1} release for t+1 period.

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Water resource calculations in the Excel

years	Time intervals: Intervals	Time intervals: Beginning of interval	Lake Baikal: Volume mln.m3	Lake Baikal: Level m	Inflow for an interval: m^3/s	Inflow for an interval: $mln.m^3$	Release for an interval: m^3/s	Release for an interval: $mln.m^3$	Irkutsk reservoir (HPP): US Level (av.) m	DS Level m	Turbine flow m3/s	Power MW	Electricity generation billion kWh
	initial volume		[illegible]	[illegible]									
2016 - 2017	V 1-10	01.05.2016	16 802	455.53	2 123	1 834	1 300	1 123	454.42	425.83	1 296	313.0	75.1
	V 11-20	11.05.2016	17 333	455.55	2 123	1 834	1 300	1 123	454.50	425.83	1 296	313.9	75.3
	V 21-31	21.05.2016	18 544	455.57	2 123	2 018	1 300	1 236	454.59	425.83	1 298	314.8	83.1
	VI 1-10	01.06.2016	16 826	455.60	3 990	3 447	1 300	1 123	454.73	425.83	1 296	316.7	76.0
	VI 11-20	11.06.2016	21 151	455.67	3 990	3 447	1 300	1 123	454.98	425.83	1 298	319.1	76.6
	VI 21-30	21.06.2016	23 475	455.75	3 990	3 447	1 300	1 123	455.15	425.83	1 298	321.1	77.1
	VII 1-10	01.07.2016	25 799	455.82	2 947	2 546	1 300	1 123	455.27	425.83	1 296	322.4	77.4
	VII 11-20	11.07.2016	27 222	455.86	2 947	2 546	1 300	1 123	455.37	425.83	1 296	323.4	77.6
	VII 21-31	21.07.2016	28 645	455.91	2 947	2 801	1 300	1 236	455.46	425.83	1 296	324.5	85.7
	VIII 1-10	01.08.2016	30 210	455.96	4 123	3 562	1 300	1 123	455.57	425.83	1 296	325.7	78.2
	VIII 11-20	11.08.2016	32 649	456.04	4 123	3 562	1 300	1 123	455.70	425.83	1 298	327.1	78.5
	VIII 21-31	21.08.2016	35 088	456.11	4 123	3 918	1 300	1 236	455.83	425.83	1 296	328.6	86.7
	IX 1-10	01.09.2016	37 771	456.20	2 298	1 979	1 400	1 210	455.87	426.01	1 396	353.2	84.5
	IX 11-20	11.09.2016	38 540	456.22	2 290	1 979	1 400	1 210	455.91	426.01	1 396	352.7	84.6
	IX 21-30	21.09.2016	39 309	456.25	2 298	1 979	1 400	1 210	455.95	426.01	1 396	353.2	84.8
	X 1-10	01.10.2016	40 078	456.27	242	209	1 400	1 210	455.94	426.01	1 396	353.1	84.7
	X 11-20	11.10.2016	39 078	456.24	242	209	1 400	1 210	455.89	426.01	1 396	352.5	84.6
	X 21-31	21.10.2016	38 077	456.21	242	230	1 400	1 331	455.84	426.01	1 396	351.8	92.9
	XI	01.11.2016	36 977	456.17	-56	-73	1 400	3 629	455.71	426.01	1 396	350.3	252.2
	XII	01.12.2016	33 270	456.06	-111	-297	1 400	3 750	455.49	426.01	1 396	347.8	258.7
	I	01.01.2017	29 223	455.93	559	982	1 400	3 750	455.28	426.01	1 396	345.2	256.8
	II	01.02.2017	26 455	455.84	469	1 135	1 400	3 387	455.11	426.01	1 396	343.1	230.6
	III	01.03.2017	24 182	455.77	316	846	1 400	3 750	454.87	426.01	1 396	340.3	253.2
	IV	01.04.2017	21 279	455.68	1 189	3 059	1 400	3 629	454.67	426.01	1 396	338.0	243.4

- Start dates of periods
- Volumes in the lake Baikal at the beginning of the period
- Useful volume of inflow to Lake Baikal
- Dispatch schedule of the complex "Lake Baikal - Irkutskoye Reservoir"
- Releases from the Irkutskoye reservoir
- The Irkutskroye reservoir level depends on the level of the Lake Baikal and the release
- Downstream level of the Irkutskoye reservoir is calculated based on the existing level- release curve
- For the Irkutskaya HPP the head is calculated as the difference between upstream and downstream level. Turbine discharge and power are determined by the operational characteristics of the HPP

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The reliability of each water user requirement is calculated by the formula:

$$P= 100*M/(N+1);$$

where M is the number of calculation non failure periods, N is the total number of calculation periods in the long-term hydrological series.

Reliability standards for normal water consumption by the number of not violation years, percent:

97 - 99	Sanitary releases
95 - 99	Water supply (drinking, household, industrial)
85 - 95	Hydropower
85 - 90	Navigation (to maintain depths)
75 - 90	Irrigation and agricultural flooding
75 - 90	Fisheries

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DISCUSSION

1. Are the DS parameters (coordinates) well chosen, i.e., a valid DS solution exists, but developer has not found it.
2. How "well" are water users' requirements being met in the adopted hierarchy? Is it possible to select the DS parameters so as to improve the reliability indicators for conflicting requirements?
3. Is the DS management optimal or is it possible to achieve better results using other management tools? Does the reservoir "water capacity" of the and catchment area allow it to satisfy the water users' requirements ?

The next two reports are devoted to different approaches to building Release rules based on dispatch control schedules, which are adopted by regulatory documents in Russia. The second report is devoted to the construction of release rules based on optimization methods and the theory of trade-offs. Some definitions are repeated in the reports for better understanding

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Scheme of the "Lake Baikal – Irkutsk reservoir" complex and the location of gauging stations

Thanks for attention

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