Water Value Computation – a historical perspective

Hydro Power Scheduling Workshop 2018

Stavanger, Norway, 12-13 September

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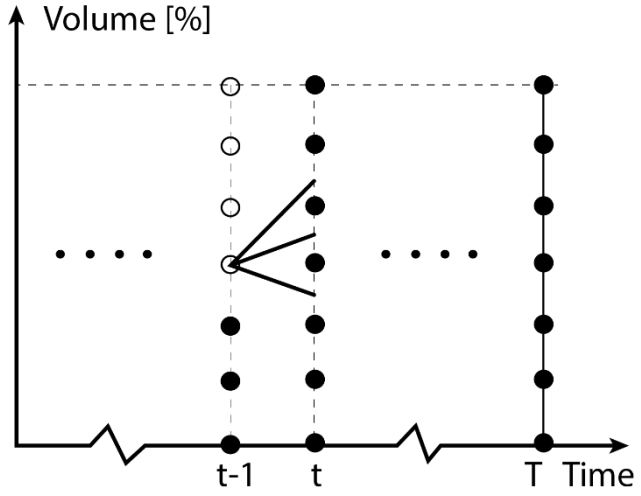
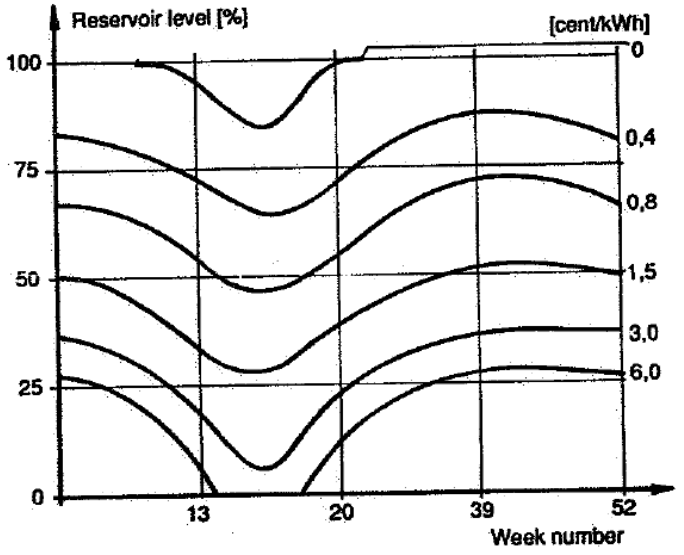
Outline of presentation

- Introduction: the water value method
- Development by Pierre Massé
- MIT and Bonneville Power, Whirlwind computer, John D. C Little
- Development in Sweden
- The water value method and further development in Norway

The Water Value Method

- The one-reservoir water value method is a fundamental tool in planning and long-term scheduling of hydrothermal systems.
- Gives expected incremental value of stored water in units of (say) øre/kWh, or grammes of coal/kWh
- Computer intensive, hence simplifications
- Gives input to more detailed models
- Works recursively in time, and can be derived from dynamic programming formalism (DP)
- However, method is older than formal DP





Pierre Massé

ALEAS ET PROGRES

Entre Candide et Cassandre

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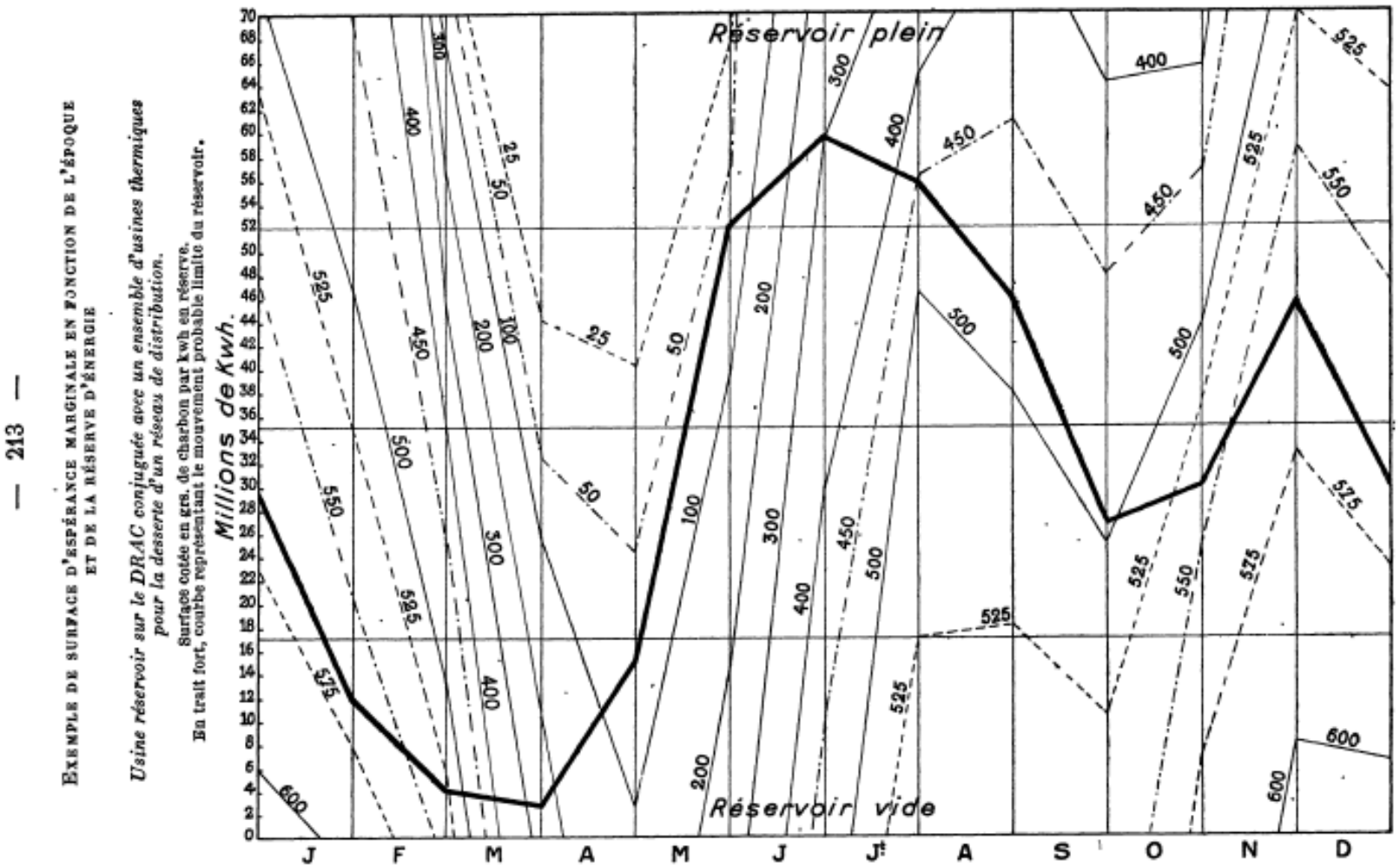
ECONOMICA

Pierre Massé – Pioneer without computer

- "Application des probabilités en chaine a l'hydrologie statistique et au jeu des réservoirs", Journal de la société statistique de Paris, tome (85), 1944, p 204-219.
- "Réserves et La Régulation de L' Avenir Dans La Vie Economique", Vol 1 & Vol 2, P. Massé, Herman & Cie, Paris 1946.
- Judy Klein Professor of Economics, Mary Baldwin College Staunton, VA 24401 USA : "Rules of Action for War and Recursive Optimization: Massé's "Jeu des Réservoirs" and Arrow, Harris, and Marschak's "Optimal Inventory Policy":
  - "It was in meeting the challenge of determining the marginal expectation of the stock of the reservoir that Massé took from his *polytechnicien's* tool bag the Markov chains of Maurice Fréchet, the log-normal distributions identified by Paul Levy and Robert Gibrat, the stochastic gaming of Emile Borel, and the recursive approximation techniques of Blaise Pascal."

Pierre Massé – 1944

According to Judy L. Klein he sketched out his procedure as early as 1940

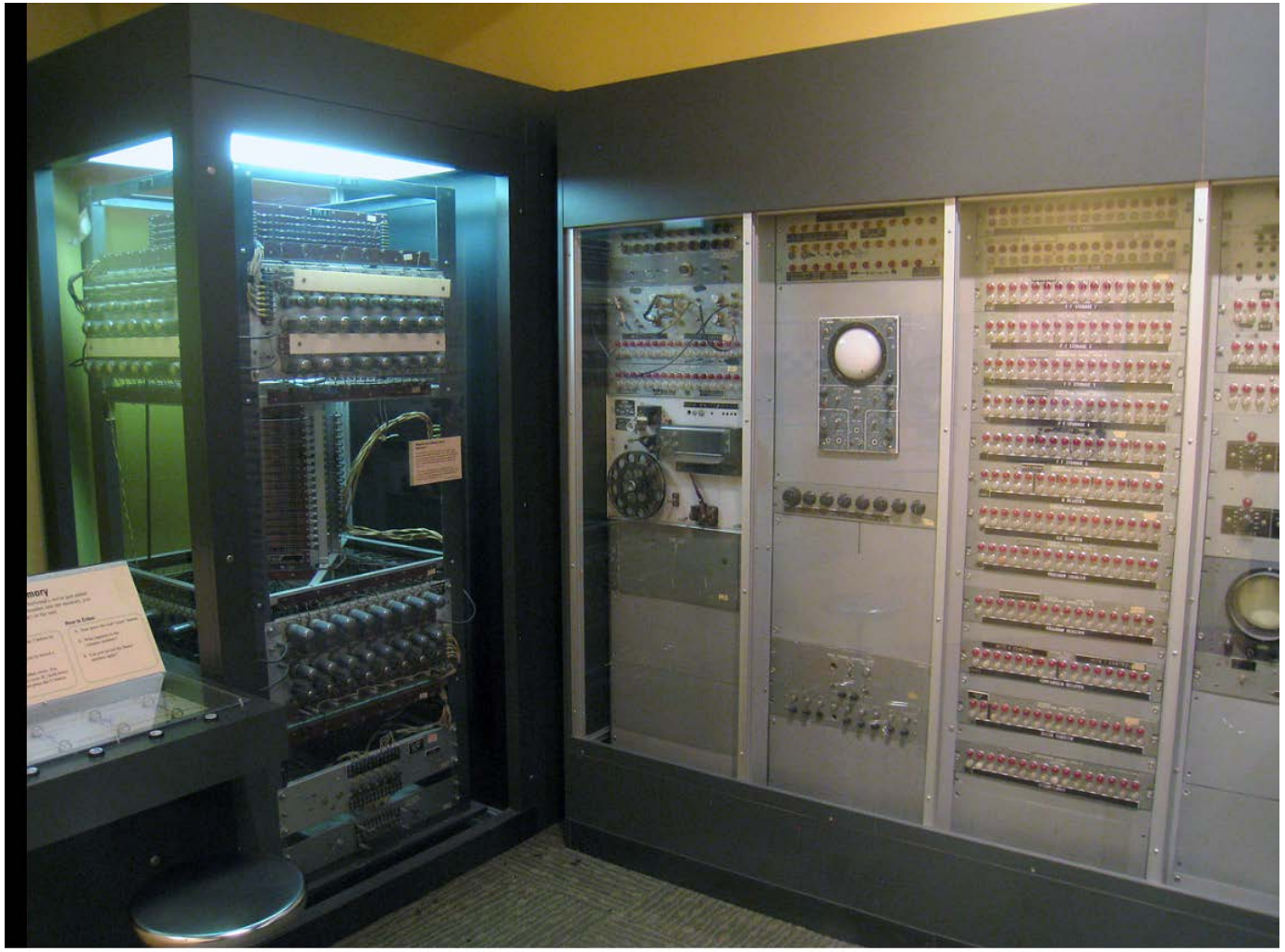


Pierre Massé – Extract from Wikipedia

- 1946, the director of electrical equipment and operations EDF
- 1948 the deputy general manager EDF.
- 1957 president of l'Électricité de Strasbourg.
- 1959 Charles de Gaulle named him Commissaire général du Plan (General Commissioner of Planning) and he held this position until 1966.
- Massé was chairman of the board of directors of Électricité de France from 1965 to 1969.
- Associate professor of la Faculté de Droit de Paris from 1965 to 1967.
- He was the first president of the Fondation de France from 1969 to 1973.
- He was elected a member of l'Académie des sciences morales et politiques in 1977.
- Pierre Massé did research in economics on the theories of economic depreciation, dynamic programming, and total factor productivity and in mathematics on Pontryagin's minimum principle.

MIT- Whirlwind I military computer

- Design 1947
- Built 1948-April 20, 1951



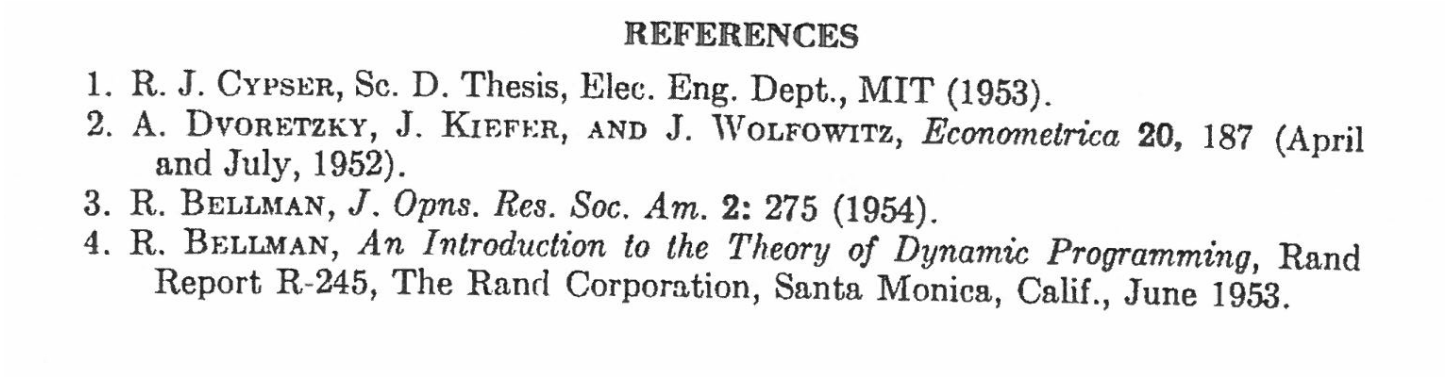
sections of core memory and controls, in Museum of Science, Boston, Massachusetts, USA.

MIT - Bonneville Power Administration (BPA)

- Rudolph John Cypser submitted his thesis for the degree of Doctor of Science to MIT in January 1953: The Optimum Use of Water Storage in Hydro-Thermal Electric Systems. He used the Whirlwind I computer and refer to collaboration with BPA:
  - 8. BOEHNE, E. W., "Incremental Loading of a Hydraulic Network," Bonneville Power Admin. Memo., Br. of Systems Engrg., BPA, Portland, Oregon. August, 1951.
  - 26. HOARD, B. V., "Economical Loading of the BPA System, Second Progress Report," Bonneville Power Administration Memo., Branch of System Engrg., December 1951.
  - 66. WEINER, I. and W. WHITBECK, "Report on Economic Loading," Br. of Systems Engrg., Bonneville Power Admin., Portland, Oregon, July 10, 1952.
  - 67. WEINER, L. and W. WHITBECK, "Short Range Economic Loading – Second Report," Office Memorandum, Br. of System Engrg., Bonneville Power Administration, Portland, Oregon, August 29, 1952.
  - 68. WHITBECK, W. F., "Economy Loading of a Multiple Dam Hydroelectric System," Report on Mathematical Classification, Br. of System Engrg., Bonneville Power Adm., Portland, Oregon, February 21, 1952.
- He also refers to the book of Pierre Massé Vol I&II from 1946.

MIT – Dynamic programming

- John D.C. Little submitted his thesis for Doctor of Philosophy in February 1954: Use of Storage Water in a Hydroelectric System
  - https://en.wikipedia.org/wiki/John_Little_(academic)
- He used Dynamic Porgramming which is closely related to the Water Value Method
- Paper based on his thesis: "The Use of Storage Water in a Hydroelectric System", Journal, Operations Research Society of America, Baltimore, Md., no. 2, May 1955, pp. 187-197
  - References: Cypser, Bellman, Dvoretzky/Kiefer/Wolfowitz



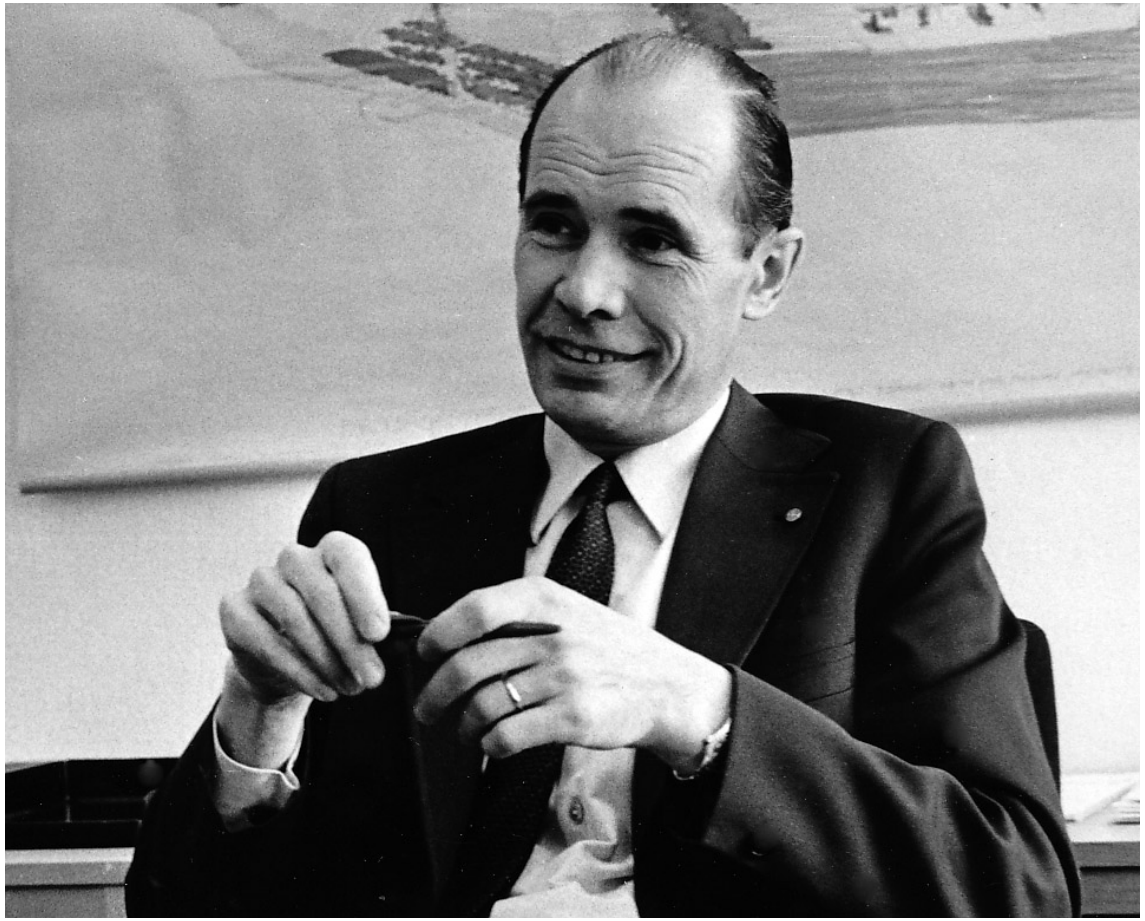
REFERENCES

1. R. J. Cypser, Sc. D. Thesis, Elec. Eng. Dept., MIT (1953).
2. A. Dvoretzky, J. Kiefer, and J. Wolfowitz, *Econometrica* **20,** 187 (April and July, 1952).
3. R. Bellman, *J. Opns. Res. Soc. Am.* **2:** 275 (1954).
4. R. Bellman, *An Introduction to the Theory of Dynamic Programming*, Rand Report R-245, The Rand Corporation, Santa Monica, Calif., June 1953.

- He used the Whirlwind I Computer

Swedish Pioneers in the period 1955-1960
Sven Stage og Yngve Larsson from Sydkraft

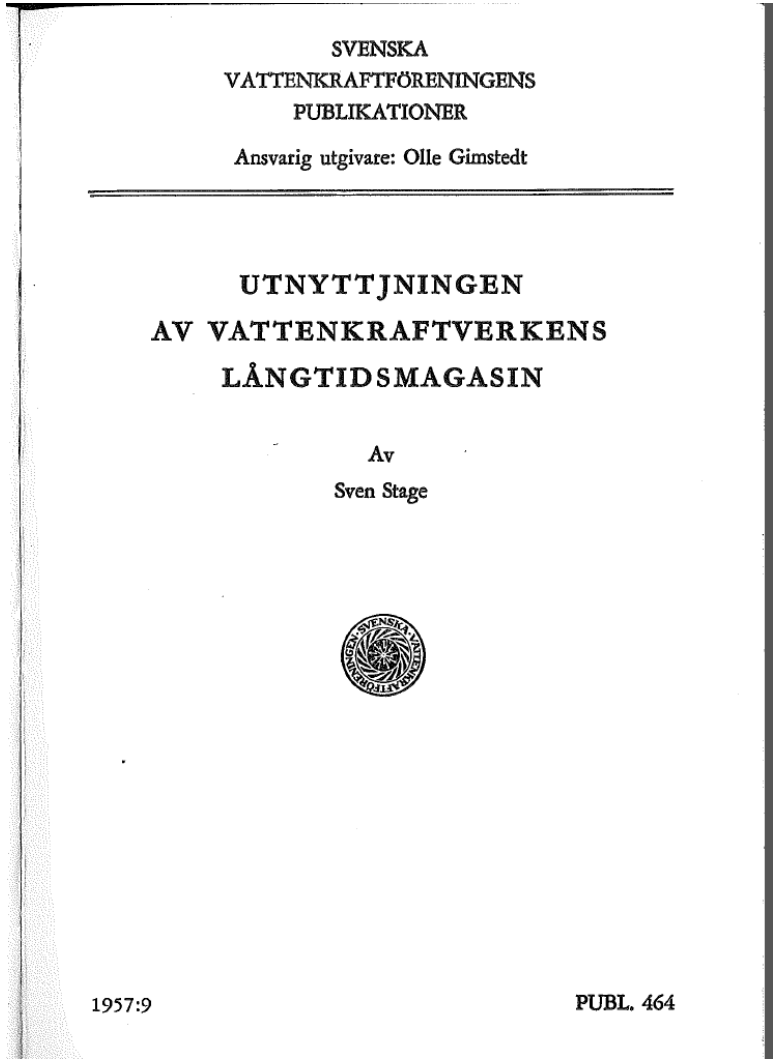
Sven Stage, born 1899



Yngve Larsson, born 1928

Stage og Larsson's introduction of water values

- Sven Stage wrote a publication in September 1957, where he involved Yngve Larsson to write appendices 1 and 2, calculation of minimum zone based on statistical methods. In Appendix 3 and 4, Stage introduces the concept of water values
- "Utilization of Long-Term Storage for Water Plants (In Swedish)", S. Stage, Publication no. 464, Svenska Vattenkraftföreningen, 1957, pp. 145-224.



SVENSKA
VATTENKRAFTFÖRENINGENS
PUBLIKATIONER

Ansvarig utgivare: Olle Gimstedt

UTNYTTJNINGEN
AV VATTENKRAFTVERKENS
LÅNGTIDSMAGASIN

Av
Sven Stage

1957:9 PUBL. 464

The Swedish computer BESK – constructed 1950-53

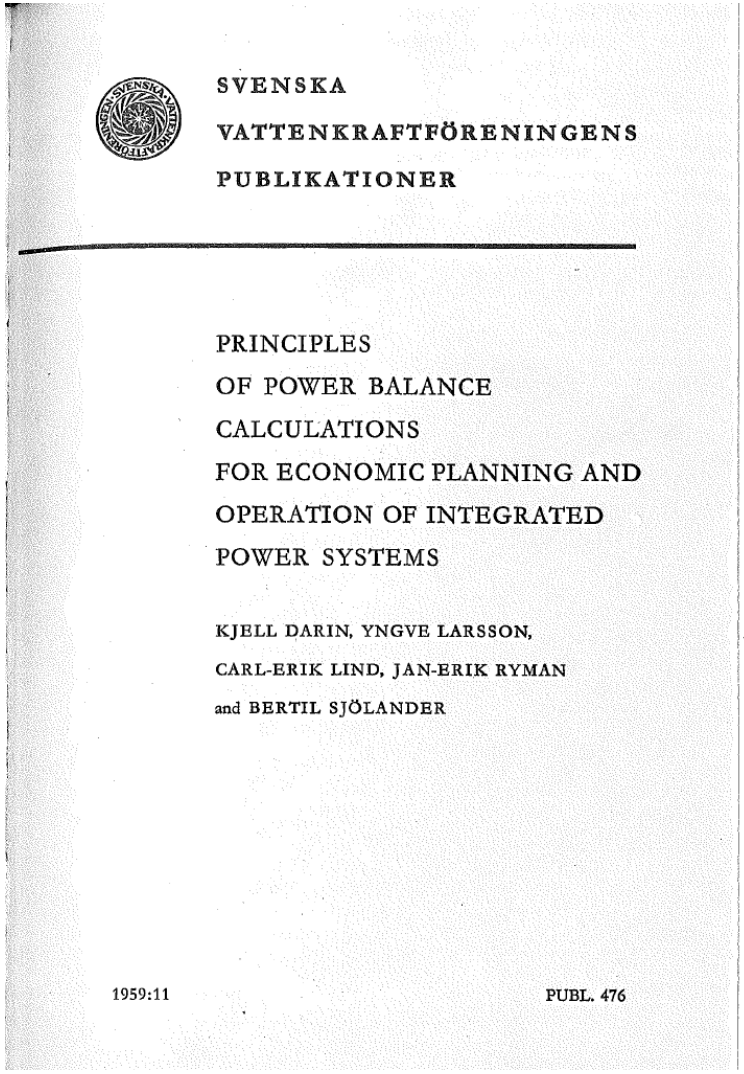
- The computer "BESK" in the old building of KTH - Royal Institute of Technology at the street Drottninggatan
- Developer: Math Machine Board (Matematikmaskinnämnden) in collaboration with KTH
- Sven Stage brought with him the young Yngve Larsson towards the end of 1956 to utilize data technology

The Power Balance Committee – 1955 Sweden

- The Swedish Power Balance Committee established in 1955, with **Jan-Erik Ryman** as leader, was based on Sven Stage's work. In essence, their inspiration was probably publication 464, 1957. Stage was not a member of this committee, but he was regularly in contact with the committee from its establishment in 1955 and informed about his theory of calculation of "minimum zone" and water value calculation
- This establishment was a result of discussions within the informal "Power Plant Club" in the Hydro Power Association where leaders of the private and municipal power companies met to discuss common questions
- The Power Plant Club saw it as important to collaborate on joint development work to assert itself against the large state power company Vattenfall

English report from November 1959 by The Swedish Power Balance Committee

- In Publication 476, which was written by the members of the Swedish Power Balance Committee and was launched by the end of 1959, is both the statistical method for calculating minimum zone and the iterative method of water value calculation presented in English



SVENSKA
VATTENKRAFTFÖRENINGENS
PUBLIKATIONER

PRINCIPLES
OF POWER BALANCE
CALCULATIONS
FOR ECONOMIC PLANNING AND
OPERATION OF INTEGRATED
POWER SYSTEMS

KJELL DARIN, YNGVE LARSSON,
CARL-ERIK LIND, JAN-ERIK RYMAN
and BERTIL SJÖLANDER

1959:11 PUBL. 476

Stage og Larsson's International Papers

- "Utilization of Long Term Storage in Combined Hydro and Thermal Power Systems", Stage, S., Larsson, Y., World Power Conference, Madrid, June, 1960. (Submitted before the report from the Power Balance Committee)
- "Incremental Cost of Water Power", Stage, S. and Larsson, Y. (August 1961): Trans. AIEE, pp. 361 – 365. This manuscript was submitted on March 21, 1960, presented at the AIEE Summer Conference 19-24, June 1960 and became available for printing on November 25, 1960. It was also presented again for discussion only at the AIEE Winter Meeting from 29 January to February 3, 1961, see the bottom of the first page of the article.

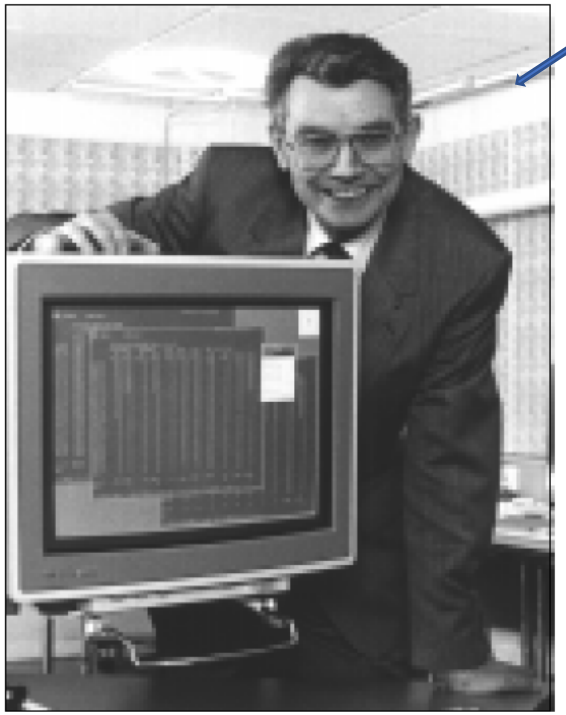
John Lindqvist (Born 1922) - Vattenfall

John Lindqvist - Vattenfall

- John Lindqvist implemented his water value method for regular operation at Vattenfall during the spring 1959.
- He presented the method in "Operation of a Hydrothermal Electric System: A Multistage Decision Process", Lindqvist, J., Power Apparatus and Systems, Part III, Transactions of the American Institute of Electrical Engineers (AIEE) (Volume 81, Issue 3), pp. 1-6, April 1962.
- The paper was submitted July 8, 1960, presented on a conference November 9-11, 1960 and made available for printing November 18, 1960, see the bottom of the first page of the article.
- Stage/Larsson submitted their AIEE article about three months before Lindqvist.
- Stage/Larsson had few references in their publications.
- Lindqvist, however, refers to P. Massé, R. Bellman, J. D. C. Little fra MIT, S. Stage and Inventory Theory by A. Dvoretzky, at al.. Lindqvist refers to a solid basis of recognized theory in both cybernetics and economics.

Göran Lindström and Jan-Erik Ryman

Scandinavian Power Company, AB Skandinaviska Elverk - SEV



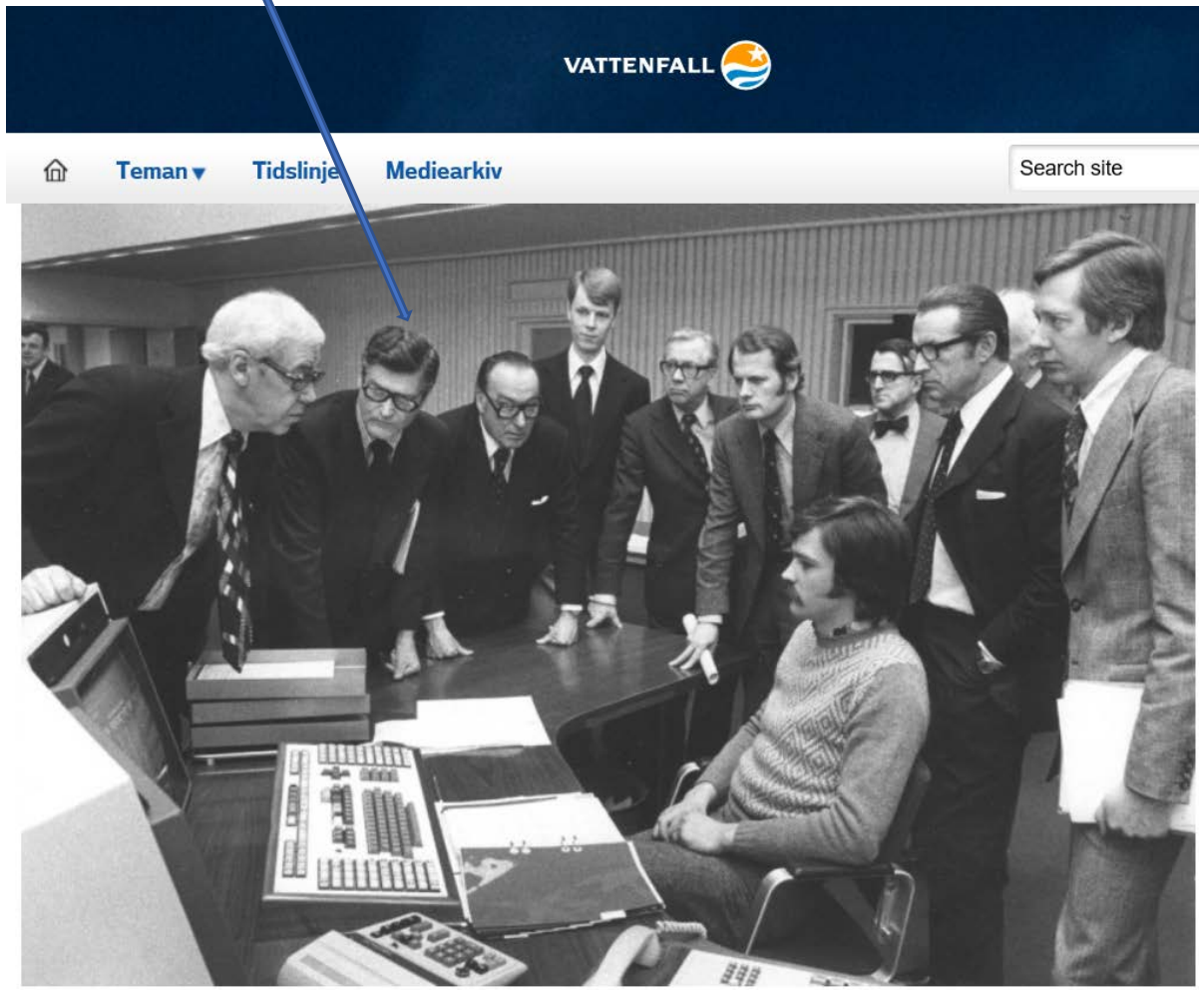
From Datsaabs history page 23-30

Göran Lindström föddes i Östersund 1932. Familjen bodde vid ett tegelbruk, där fadern var tegelmästare och i vars verkstad och smedja Göran började sin teknikerbana med att bygga cykelbilar, isjakter m. m. 1957 blev han civilingenjör vid KTH, elektroteknisk linje, kraftteknisk inriktning.

Därefter anställdes Göran på AB Skandinaviska Elverk (SEV), där han den första tiden genomlevde de äventyr som beskrivs i artikeltexten. 1969 bildades Kraftdata AB med SEV, Stockholm Stad och Krångedegruppens Samkörning AB som delägare. Göran fungerade som VD i bolaget fram till 1991 och var med om hela utvecklingen från hålremsor och hålkort till dagens lokala datorsystem och PC-tillämpningar.

Sedan 1991 är Göran seniorkonsult med inriktning på nya tillämpningar för den kommande avreglerade elmarknaden.

Fritiden ägnas åt familj och sommartorp i Sörmland, renovering av en liten gård i Jämtland, promenader, fjällvandring, skidåkning och långfärdsskridskor.



Tidas invigs 1977
Med på bild finns bland annat Jonas Norrby, Jan-Erik Ryman, Gunnar Ålfors, Olof Johansson, Curt Nicolin och Sivert Göthlin.
År: 1977 | Plats: - | Skapare: Okänd | ID: vf200094

Swedish commercialization

Jan-Erik Ryman and Göran Lindström, AB Skandinaviska Elverk - SEV

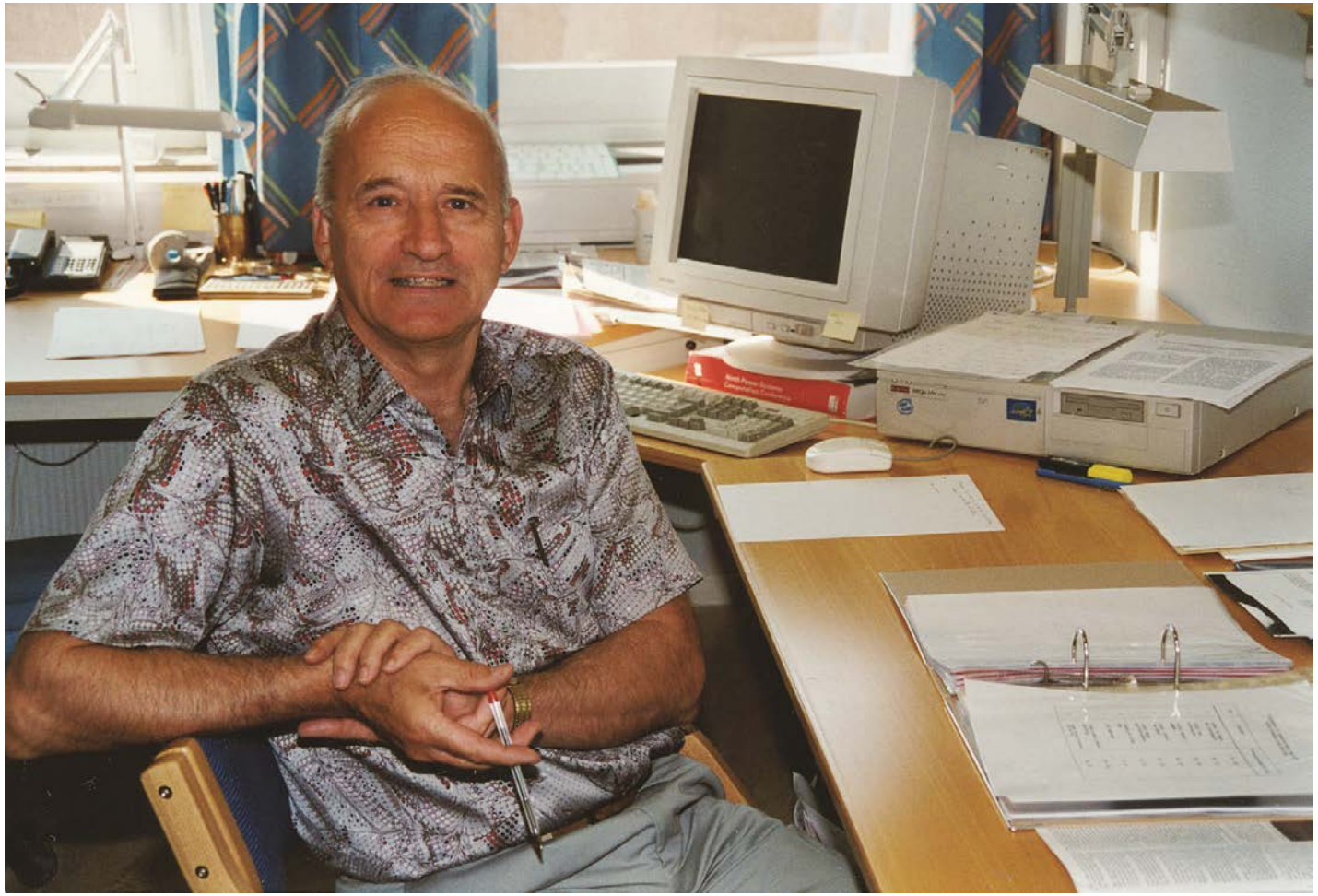
- Göran Lindström graduated at KTH in 1957 and started his first job at Scandinavian Electricity Company - SEV under the leadership of Ryman.
- He completed a three-week course in the programming of Facit EDB3 (successor to BESK).
- When he started working, he was placed on the task of solving long-term allocation of SEV's hydropower resources in combination with thermal power.
- Lindström got a solution to the task on a Facit EDB3 early in 1958.
- Ryman persuaded the management of the company and SEV and DATASAAB began a dialogue in 1958/59 on the development of a new computer. This led to the fact that SEV had installed the first SAAB D21 computer in the spring 1962.

Commercialization of the Swedish Code.

- In 1969, the development of the computer code had become a success, and SEV established the company Kraftdata AB together with Stockholm City and Krångedegruppens Samkörning AB.
- Göran Lindström became President of Kraftdata AB and was in this position until 1991.
- The water value model was called KR63 and later KR70.
- Today it has the name KR90 and is managed by the company Tieto, which has a few customers in Sweden for this program system.

Arne Johannesen

SINTEF Energy Research, Norway



Arne Johannesen, born 1931

- Employed at EFI (today SINTEF Energy Research) in the fall 1961 after two years of continuing studies at the University of Alberta, Edmonton, Canada - where he learned computer programming.
- When he joined EFI in Trondheim, he immediately started developing a water value model on a Ferranti computer (named Frederic) at the Norwegian Defense Establishment, FFI, at Kjeller.
- He went by train about 500 km to Kjeller, close to Oslo, to run the program.
- He wrote the report: "Long-term planning for operation of interconnected hydropower plants (one-reservoir model), EFI-TR No. 1177, Case 22U-l, Completed 16.11.62 (TR A1177).
- Arne preferred Lindqvist's problem formulation and solution.

The Norwegian lexicon "Store Norske Leksikon" about Frederic

- FREDERIC was a digital tube-based computer in use at the Norwegian Defense Establishment (FFI) between 1957 and 1964. This was the most important computer in Norway in the late 1950s, ensuring that FFI had long the country's heaviest IT environment.
- FREDERIC was the first of 19 Mercury computers, provided by the British electronics company Ferranti. This was one of the first computers in the world based on series production.
- Merkury was developed as a collaboration between Ferranti and the University of Manchester, and was a further development of Ferranti Mark I from 1951. The work on Mercury started in 1953, but improved seriously after Jan V. Garwick ordered a machine for the Norwegian Defense Establishment (FFI) in 1954.

The computer Frederic at Kjeller in Norway

Ingeniør Bakke foran konsollen til den elektroniske regnemaskinen FREDERIC, fotografert på Kjeller, 25. mars 1966. Datamaskinen FREDERIC av Rolf A. Strøm/Norsk Teknisk Museum. CC BY SA 3.0

Further development at EFI

- 21. Nov. 1962 the computer Gier arrived at The Norwegian Institute of Technology (NTH) in Trondheim , and in 1965 a Univac 1107, establishing the computer age at NTH and SINTEF.
- In 1977 EFI started using a Nord 10/S computer for water value computations. Nord 10 was launched in 1973 and the upgraded version Nord 10/S arrived in 1975.
- From the 1970s, the EFI one-reservoir model was further developed by Jan Hegge, Rolf Reitan, Henrik Evenrød, Erling Kylling, Arne Haugstad and others.
  - Main result was EMPS; a multiarea model with a one-reservoir representation of each area, extensively used in Nordic countries
- A new multireservoir model based on Pereira & Pinto's stochastic dual dynamic programming (SDDP) uses water values from the multiarea model as input.

Vidkun Hveding The Norwegian Water Resources and Energy Directorate (NVE)
Jan Husebye Norwegian Computing Center (NR)

The NVE model

- The NVE model was developed by NR and NVE and was used by NVE in the period 1963-1975. The optimization part was developed by Jan Husebye and the simulation part by Johan Rieverts.
- International publication by Hveding: "Digital simulation techniques in power system planning", V. Hveding, Economics of Planning 1968;8(2):118–39.

Status and trends

- Water value computations in some form are essential for long-term hydropower scheduling:
  - Increased competition; more need for decision tools
  - In the Nordic countries, the SINTEF water value-based multi-area model (EMPS) is used by many companies.
- Other, detailed models exist for seasonal and short-term scheduling.
- Trends in model development
  - More detailed models (faster computers, parallel processing)
  - More stochastic variables, multimarket
- Possible extensions of the classical one-reservoir model water value model:
    - Inflow state, more than one reservoir

Some publications

- "Application des probabilités en chaine a l'hydrologie statistique et au jeu des réservoirs", Journal de la société statistique de Paris, tome (85), 1944, p 204-219.
  - http://www.numdam.org/article/JSFS_1944__85__204_0.pdf
- "Réserves et La Régulation de L' Avenir Dans La Vie Economique", Vol 1 & Vol 2, P. Massé, Herman & Cie, Paris 1946.
- Judy L. Klein om Pierre Massé. *Rules of Action for War and Recursive Optimization: Massé's "Jeu des Réservoirs" and Arrow, Harris, and Marschak's "Optimal Inventory Policy"* (Bib)
  - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.416.2140&rep=rep1&type=pdf
- Some Scandinavian and English publications to the left on this Web page:
  - https://brage.bibsys.no/xmlui/handle/11250/2397393
  - One of the documents above includes links to many other documents: https://brage.bibsys.no/xmlui/bitstream/handle/11250/2397393/Link%20til%20noen%20sentrale%20artikler%20p%c3%a5%20Internett.pdf?sequence=46&isAllowed=y