NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
VASSDRAGSDIREKTORATET
HYDROLOGISK AVDELING

JOINT TIME SERIES ANALYSIS OF PRECIPITATION, RIVER DISCHARGE AND ENERGY PRODUCTION

Utarbeidet ved Institutt for geofysikk og Hydrologisk avdeling
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PREFACE/FORORD

Trends and cyclic variations in long time series of hydrology and meteorology are important for planning future hydro power development and production. This report presents the results of a preliminary study of long observationed series of runoff, precipitation and energy production.

Som et av grunnlagene for Energimeldingen i 1986 ble det foretatt en undersøkelse av lange tidsserier for avløp, nedbør og energiproduksjon. Undersøkelsene er foreløpige, fordi de baserer seg på et begrenset antall med serier fra hele landet. De gir imidlertid et verdifullt grunnlag for å trekke sine slutninger når det gjelder serienes variasjoner over lengre tidsrom.

Oslo, november 1984

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1. INTRODUCTION

In order to evaluate the representativity of the time periods used to estimate the mean potential energy production in Norway, a joint time series analysis has been performed. The analysis included six long precipitation series (table 1), 16 long river discharge series, four for each hydropower district (table 2) and three series of calculated energy production.

The first energy production series, denoted (A), is the observed production for all of Norway. No corrections for spill in flood periods have been made. Data are calculated for the period 1931-1980. The series (B) for the period 1931-1980 is the sum of discharge from a one storage model developed for the fourth hydropower district. The production is based on an assumed production potential for the year 1990. Corrections for spill are included. The third series (C) are the results of simulations with the "Samkjøringsmodellen" for all of Norway. The simulation has been made with the hydropower system of 1983 for the period 1931-1960.

Table 1. Precipitation series used in the study, yearly values for hydrological years.

Station		Period
1010	Os i Østerdal	1895-1983
3922	Mestad i Oddernes	1900-1983
4289	Skreådalen	1895-1983
5035	Samnanger	1901-1983
6833	Lien i Selbu	1895-1983
8350	Kråkmo	1895-1983

Table 2. River discharge series used in the study, yearly values for hydrological years.

Station		Period	Catchment area km^2
Region 1			
388-21	Elverum	1871-1980	15356
412-22	Losna	1896-1980	11087
458-22	Krøderen	1899-1980	5094
548-21	Kjølemo	1896-1980	1740
Region 2			
598-21	Bulken	1892-1980	1071
567-21	Bjerkeland bru	1896-1980	194
568-21	Bjerkreim bru	1897-1980	633
582-21	Suldaloset	1904-1980	1308
Region 3			
383-22	Aursunden	1902-1980	830
661-22	Haga bru	1908-1980	3080
697-22	Åbjørvatn	1908-1980	384
1413-22	Rathe	1881-1980	3049
Region 4			
757-21	Malangfoss	1911-1980	3113
729-22	Kobbervatn	1916-1980	838
770-23	Skoganvarre	1921-1980	943
772-21	Polmak	1911-1980	14147

2. PRECIPITATION

Mean yearly values, standard deviations and coefficients of variation for the six precipitation stations are shown in table 3. The gradients in precipitation pattern are very large in Norway. The low coefficients of variation indicate stable climatic conditions.

The large differences in annual means is because Norway has a rather complex climate. Therefore the inter station correlation is very low (table 4). The independence of annual precipitation, that table 4 indicate, makes the propability that the whole country at the same year should have dry, normal or wet conditions relatively small.

Table 3. Mean values, standard deviations and coefficients of variation of yearly precipitation (hydrological years).

Station nr.	mean (mm)	std.dev. (mm)	coeff. of var.
1010	455	73	0.16
3922	1648	326	0.20
4289	1994	379	0.19
5035	3230	660	0.20
6833	825	127	0.15
8350	1312	289	0.22

Table 4. Inter station correlation of yearly precipitation (hydrological year)

Station nr.	1010	3922	4289	5035	6833	8350
1010	1					
3922	- 0.08	1				
4289	0.18	0.39	1			
5035	0.25	- 0.15	0.68	1		
6833	0.42	- 0.41	0.11	0.42	1	
8350	0.06	- 0.40	0.14	0.52	0.34	1

3. RIVER DISCHARGE

The analysis of river discharge series confirms the conclusions from the precipitation analysis. The variations in mean values is of course dependent mainly on the size of river basins (table 5). The coefficient of variation, however, show very stable values around 0.2. This is a reflection of the climatic stability. This coincidence between variability in annual precipitation and in river discharge is among the Nordic countries spesific for Norway and the Northern inland parts of Sweden and Finland. In other parts of the Nordic countries and in Nothern Soviet Union conditions are less stable with higher coefficients of variation. This phenomenon was studied and commented on in an earlier work by Gottschalk et.al., presented in the periodical Nordic Hydrology.

As the number of station were relatively large and organized in four regions the inter station correlations were averaged for each region. The correlations in the diagonal in table 6 is thus average correlations between regions. From the table it is confirmed that the correlation between regions are low. The within-region correlations are high, except for region four. Regions one to three can thus be considered homogeneous with respect to yearly variation patterns in river discharge. This is not valid for the fourth region which is highly non-homogeneous as indicated by the series used in the study.

The tables show that the coefficients of variation of the investigated runoff and precipitation series are low and stable. This is again a good indication on the relatively stable climatic regime in Norway as a whole.

Similar investigations in other countries and parts of the world may show much higher values of the coefficients of variation. This is specially valid in the tropical and sub-tropical areas. In our latitudes we find an increase in values as the climatic becomes more continental. This may be the reason for the high value for Skoganvarre in Finnmark. One should also expect a high value for Polmak in Finnmark. However, this is one of the greatest catchment in the investigation. One may suggest that this big catchment dampens the annual runoff and therefore the annual variation. We suggest that the catchments in the inner parts of Finnmark belongs to a more continental regime than the northern and western parts of region four. Region four is thus non-homogeneous concerning its climatic conditions. This fact is supported by a number of other Norwegian and Nordic investigations on runoff and precipitation series.

Table 5. Mean values, standard deviations and coefficients of variation of yearly river discharge (hydrological years).

Region	Station nr.	Mean		Std.dev.		Coeff. of. var.
		(m^3/s)	mm	(m^3/s)	mm	
1	388-21	247	507	44	90	0.18
	412-22	248	705	35	100	0.14
	458-22	118	730	24	149	0.20
	548-21	83	1504	18	326	0.21
2	598-21	64	1884	13	383	0.20
	567-21	14	2276	2.6	423	0.19
	568-21	55	2740	11	548	0.20
	582-21	89	2146	18	434	0.20
3	383-22	20	760	3.6	137	0.18
	661-22	80	819	17	174	0.22
	697-22	31	2546	6.0	493	0.19
	1413-22	103	1065	22	228	0.21
4	757-21	86	871	17	172	0.20
	729-22	26	978	6.6	248	0.25
	770-23	16	535	9.6	321	0.60
	772-21	158	352	33	74	0.21

Table 6. Average correlations of yearly river discharge within diagonally and between regions.

Region	1	2	3	4
1	0.76			
2	0.53	0.82		
3	0.01	0.42	0.83	
4	- 0.04	0.18	0.35	0.06

As we below will consider the energy production regionwise it is of interest to calculate the yearly variability of the sum of discharge for a region.

We have already stated that the coefficient of variation is almost constant equal to 0.2. If all stations were totally correlated the sum of discharge would also have a coefficient of variation to 0.2. This is not so, the coefficient of variation for the sum of discharge will be somewhat lower than 0.2. How much is dependent on the within-region correlation between stations and also, but to a lesser extent, the number of stations. Utilizing the average values in table 6 it may be shown that the reduction for regions one, two and three is approximately 0.20 to 0.18 and for region four from 0.20 to 0.08 - 0.11 due to very low correlation there.

Much discussion have been made in Norway on the representativiness of the very dry years 1941-42. Are these years representative for the kind of climate we now have? Did the whole country experience the same dry period? Are there other bad combinations of dry years observed during the last 100 years?

These questions were analysed by Wingård and Roald in 1976 ("Catchments in South Norway - has it ever been as dry as this year?", in Norwegian). The driest, two driest and three driest years in the period 1915-75 in 42 catchments in South Norway and Trøndelag were investigated.

The analysis shows that 1940-42 were the three driest years in the central parts of Østlandet and Sørlandet.

The coastal areas of Østlandet had the driest years in 1971-73, and the coastal parts of Vestlandet in 1958-60. The same combination of dry years in Trøndelag happened in 1935-37, while the mountains between Østlandet and Telemark had this period during 1969-71. The analysis also concluded that the driest observed yearly runoffs in the 45 catchments were close to the expected values.

Dry years do not occur at the same time in the various parts of Norway. This study supports our finding of poor correlation between the various regions. The observed combination of the dry years 1940-42 for Østlandet and Sørlandet (which are within the same region) should therefore not be considered as a very rare event.

4. ENERGY PRODUCTION

The statistical parameters of the different energy production series are shown in table 7.

Table 7. Mean values, standard diviations and coefficients of variation of yearly energy production.

Series	Mean (TWh)	std.dev. (TWh)	coeff. of. var.
A (all Norway)	106	14.4	0.13
B (region 4)	8.7	1.2	0.14
C (region 1)	44	4.2	0.09
C (region 2)	28	2.8	0.10
C (region 3)	20	1.5	0.07
C (region 4)	5.0	0.4	0.07
C (all Norway)	98	6.1	0.06

Interesting to note is the difference between the series A and C for all Norway. This difference is just below 9%, and represents the losses due to spill during flooding. The coefficients of variation of series C are also lower, because a hydro power regulation smooths out the natural runoff.

It has already been stated that the variability should be reduced when we sum up for regions and for Norway as a whole. The effects, however, are larger than can be expected from summation. It is also to be expected that the variability will still further be reduced when taking into account losses. The low figures of annual variation in energy production series can possibly indicate that the present methodology to calculate energy production do not fully preserve the true variability. For instance the scaling that is made of river discharge series compensate for differences in means but not for differences in variances. The effect of too low yearly variability in energy production is that we will overestimate the precission in the long term average energy production.

The correlation of energy production in different regions was also analysed and the results are shown in table 8. It can be compared with table 6. There are some common patterns but also differences. To some extent these differences can be explained by statistical errors. Other differences, as the decrease of the correlation between regions two and three and the increase in correlation between regions three and four must be explained by differences in how the energy systems operate compared to the natural river discharge. We can note that the correlation between regions one and two is the same in the two tables. An other explanation can be that the simulation models used do not fully preserve statistical properties of the actual energy-production series.

Table 8. Correlation coefficients of energy productions in different regions. (Series (C)).

Region	1	2	3	4
1	1			
2	.53	1		
3	- .25	- .13	1	
4	- .16	- .03	.74	1

5. JOINT ANALYSIS

As a first step yearly precipitation and river discharge were studied together. Correlation coefficients are shown in table 9. For river discharge the coefficients have been averaged for regions.

Table 9. Average correlation coefficients between regionwise river discharge and precipitation.

Region	Precipitation station					
	1010	3922	4289	5035	6833	8350
1	0.20	0.65	0.57	0.27	- 0.08	- 0.19
2	0.09	0.24	0.84	0.80	0.25	0.26
3	0.35	- 0.37	0.28	0.61	0.79	0.53
4	0.03	- 0.19	0.12	0.25	0.31	0.39

Precipitation series usually has the longest period of observations. Table 9 indicate that with a good choice of yearly precipitation series annual runoff series can be extended to represent a longer period of observations. The problem needs, however, to be further studied especially the non-homogenity of variation patterns in region four.

As the amount of data was rather large and contained much redundant information, a principal component analysis (empirical orthogonal functions) was applied. This means that new data series were created as linear combinations of existing series. The new series are calculated in such a way that they are independent and ordered in accordance with the amount of total variance they contain. These new series created from precipitation and/or river discharge series were then correlated with the energy production series. The model to extend annual energy production series E(t) as a function of time is thus

$$E(t) = \overline{E} + \sigma_E \sum_{i=1}^{M} \rho i \ \beta i \ (t) + \varepsilon(t)$$

where E is the average energy production, σ_E its standard deviation, σ_i the correlation coefficient between E(t) and the orthonormal amplitude function β_i (t) with the order i. The number of amplitude functions M is chosen so that the significant part of the variance is accounted for. ε(t) is an error term. In figures (1) and (2) are two examples shown. The multiple correlation for the two cases are 0.82 and 0.73 respectively. The same type of analysis was done for all discharge series (multiple correlations 0.73-0.80) for all precipitation series (multiple correlations 0.66-0.69) and for the joint discharge and precipitation series (no gain in relation to only discharge series). The analysis was also performed region for region with multiple correlations from 0.87 to 0.96 for regions one to three but only 0.56 for region four. The conclusion that can be drawn is that there is a lot to gain by regional analysis.

The results presented here must be seen as preliminary. The precipitation and river discharge data analysed are very small compared to the total amount of data available. There is a need to analyse these type of data with respect the to representativity in space and time as well as their regional homogenity. It is further suggested that the methodology presented here, to extend series and to fill in gaps in series, which can preserve mean values, variances and also inter station correlation, should be further developed to be used as a standard tool for these purposes.

6. YEARLY AVERAGE ENERGY PRODUCTION

The extended series can be used to evaluate the representativity of the periods for which energy production are available. The effective number of years, n_e, represented in the extended series with respect to average values can be approximately evaluated from the following expression:

$$n_e = \frac{n}{1 + (1 - \frac{n}{N}) \left(\frac{1 - (n-2) \cdot R^2}{n-3}\right)}$$

where n is the available period of energy production, N the period of river discharge and/or precipitation series and R the multiple correlation coefficient.

The standard errors d_E in estimated averages, can now be calculated as $d_E = \sigma_E / \sqrt{n_e}$. The confidence limits are = 1.96 x d_E around the mean value (95% confidence level).

Estimated averages from extended series, as well as the effective number of years and 95% confidence limits for the average are given in table 10. Comparing tables 10 and 7 reveals that the extra information gained from the extended series are neglible. The fact that the series 1931-80 and 1931-60 are representative for a longer period is of course a coincidence and should not tempt us not to use as long periods as possible in such important simulations. One should always use as long observation series (of good quality) as possible not to loose information.

Willén studied the representativity of Norwegian hydrological series in Rapport nr. 1-81 from NVE-Hydrological Division. He also found that the period 1931-60 is to a great extent representative of the longer observed series extending back to the beginning of this century. The differences observed are not greater than may be expected in two such series. However, dry years have somewhat lower values than may be expected in Regions 1 and 2. The difference is only 2%, but represent in terms of energy-production

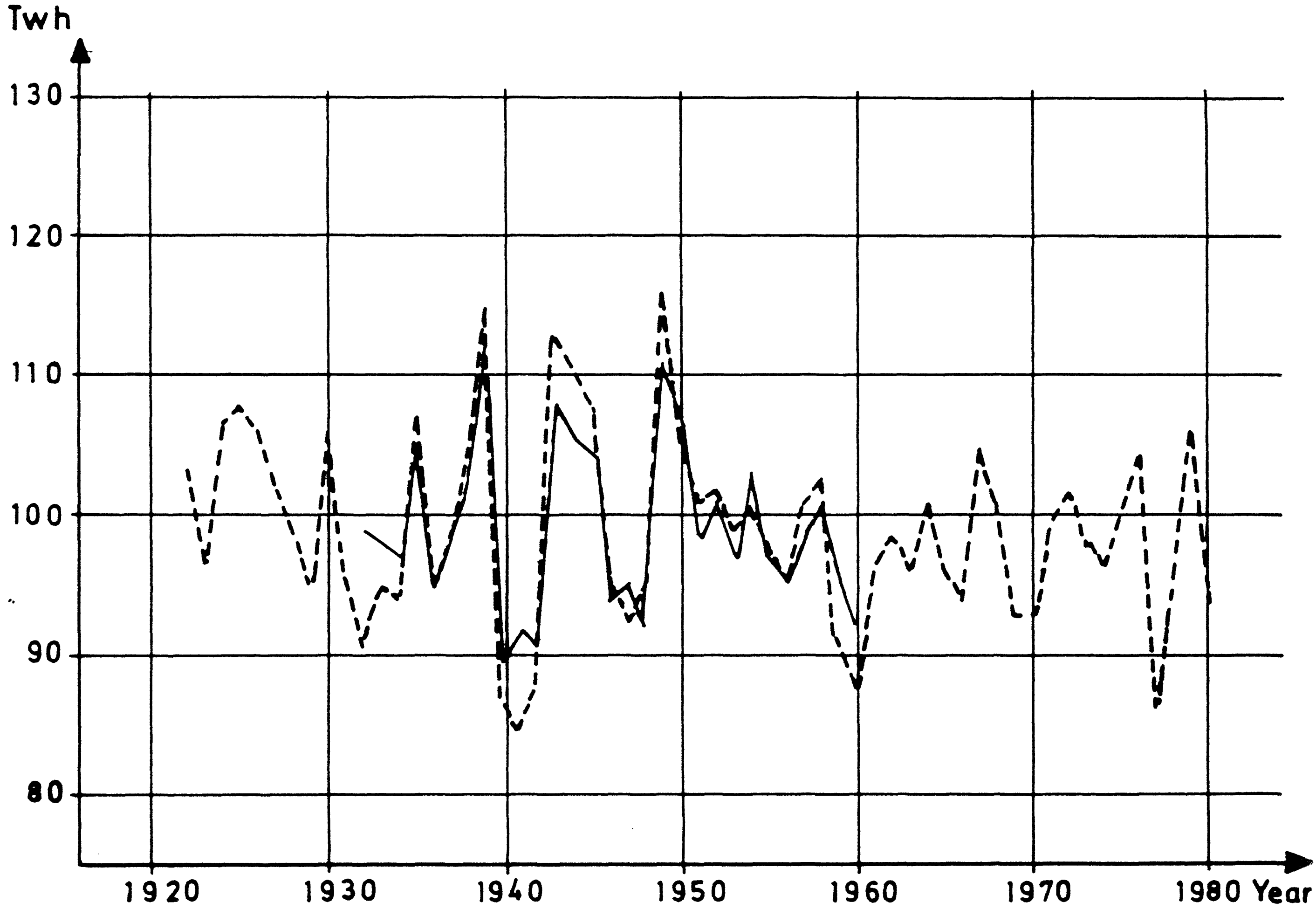

Figure 1 Energy production series (C) for all of Norway (———) and extended series (- - -) by means of principal component analysis of 16 river discharge series.

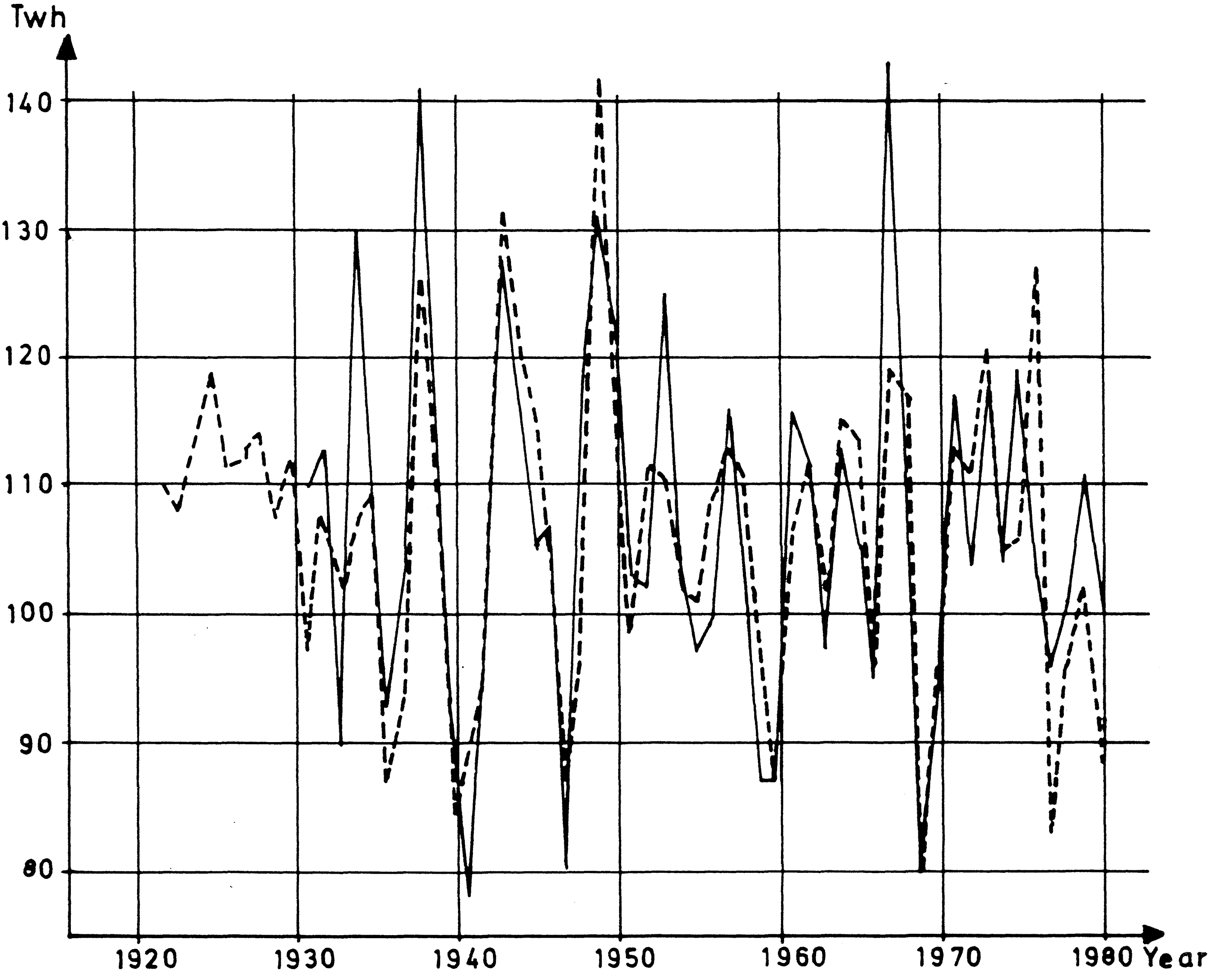

Figure 2 Energy production series (A) for all of Norway (———) and extended series (- - -) by means of principal component analysis of 16 river discharge series.

a considerable amount of hydropower. On the other hand, we agree with Willén that so small differences should not be used to correct our present energy-simulation in view of the great variation of the dry year values.

Table 10. Estimated average energy production E, with confidence intervals and effective number of observation years n_e.

	Series	Yearly energy production TWh			No. of observation years	
		Simul. mean	Extend. mean	Confidence interval (95%)	simul.	effec., extended
i)	A (all Norway)	106.7	108	103 - 112	50	55
i)	B (region 4)	8.7	8.7	8.4 - 9.0	50	55
	C (region 1)	44.5	44	43 - 45	30	71
	C (region 2)	28.8	28	27 - 29	30	54
	C (region 3)	20.2	20	19 - 21	30	41
	C (region 4)	5.0	4.9	4.8 - 5.0	30	35
ii)	C (all Norway)	98.2	98	96 - 99	30	50
iii)	C (all Norway)	98.2	98	96 - 100	30	44
iv)	A (all Norway)	106.7	106	102 - 110	50	61
iv)	C (all Norway)	98.2	98	96 - 100	30	42

i) Estimated from river discharge
ii) Sum of regions
iii) Joint for whole Norway
iv) Estimated from precipitation

Willén found also some trends in parts of the data series. He gives examples of decreasing yearly runoff during the period 1920-66. He also found increasing winter runoff during this period, and decreasing summer runoff. For the whole observed period neither Willen nor we have traced indications of trends in the series. This also supports our advice of always using as long observed or otherwise simulated hydrological series as possible when energy production is concerned. This is the best way of avoiding trends in a smaller period, or non-representative combinations of dry and wet years.

The confidence limits in table 10 (shown in size 17) are very narrow. The model used here preserves the variance in the same way as the original series. The comments above of the risk of overestimation of the precision in average values is valid for the values given in the table especially concerning the series (C).

7. SUMMARY (IN NORWEGIAN)

Er det store årlige variasjoner i det hydrologiske tilsigsmaterialet? Vil energiproduksjonen bli forskjellig hvis vi legger andre simuleringsperioder til grunn for beregningene? Kan vi stole på grunnlagsmaterialet?

Disse spørsmålene kan vi få svar på ved å studere lange serier av årlig nedbør, tilsig og simulert energiproduksjon. Vi har tatt for oss seks nedbørserier og 16 hydrologiske tilsigsserier jevnt fordelt over landet. Alle seriene har data fra begynnelsen av dette århundret og frem til idag. Disse tidsseriene har vi sammenliknet innbyrdes både for hele landet under ett, og for hver av de fire samkjøringsregionene. Vi har også sammenliknet dem med simulert energiproduksjon for perioden 1931-80 (uten korreksjon for flomtap) og for perioden 1931-60 (simulert 1983-systemet ved bruk av Samkjøringsmodellen). Begge seriene gir middeltall for hele landet, og den siste serien i tillegg middeltall for hver samkjøringsregion.

Analysen av nedbørseriene viser at vi har stabile klimatiske forhold i Norge. Det er imidlertid store forskjeller i årsmidler mellom nedbørstasjonene. Denne lave samhørigheten viser at det er liten sannsynlighet for at hele landet i et og samme år enten vil få liten, normal eller høy årlig nedbør.

Samhørigheten mellom tilsiget i de enkelte regionene er høy, unntatt for Region 4. Dette viser at samkjøringsregionene er ganske homogene hva gjelder årsavløpet. Region 4 er enten ikke-homogen (den kan eventuelt deles opp i to eller flere underregioner), eller de valgte hydrologiske serier er lite representative. Vi mener at særlig i Nord-Troms og Finmark bør man være særlig oppmerksom på den brå overgangen mellom kyst- og innlandsklimaet, og heller til den oppfatning at regionen i seg selv ikke er homogen. Samvariasjonene mellom Region 1 og Region 2 er ganske god, og heller ikke uvesentlig mellom Region 2 og Region 3. Samvariasjonen mellom andre kombinasjoner av regioner er dårlig. Dette bekrefter det inntrykket nedbøranalysen ga.

Samhørigheten mellom nedbør og avløp innen hver region er så god at med et fornuft valg av stasjoner vil vi kunne utvide avløpsseriene utover sine observasjonsperioder ved å bruke nedbørseriene som forklaringsvariable.

Serien for energiproduksjon er beregnet ved hjelp av samkjøringsmodellen basert på produksjonssystemet slik det var pr. 1983. Disse produksjonsdata er således ikke observerte data. Serien for energiproduksjonen i hver region viser ikke det samme variasjonsmønstret som vi har i seriene for tilsig og nedbør. Produksjonsseriene viser en lavere variasjon. Årsaken til dette kan være:

- Den fysiske begrensningen i produksjonssystemet medfører relativt mye større flomtap i våte år enn i normale år.

- Våte år gir høy magasinfylling som overføres til neste års produksjonsdata.

I enhver simulert produksjonsserie som er basert på ukeverdier vil flomtapet bli underestimert og middelproduksjonen overestimert.

Produksjonsserien for hele Norge viser en lavere variasjonskoeffisient enn seriene for de enkelte regioner. Dette er rimelig siden hele landet ikke blir berørt av våte eller tørre år samtidig.

Simuleringsperiodene for energiproduksjonen (1931-80 og 1931-60) er representative for lengre perioder. Det har ikke vært kombinasjoner av tørre eller våte år tidligere i dette århundret som skiller seg fra de vi har hatt i disse to seriene. Vi vil imidlertid anbefale at man bruker så lang simuleringsperiode som mulig når produksjonspotensialet skal beregnes for ikke å miste verdifull informasjon. Disse konklusjoner gjelder både for landet som helhet og for hver region.

Produksjonspotensialet bør ikke fastsettes ved middeltall. Til det er usikkerheten forbundet med produksjonsberegningen for store. Dette kommer til uttrykk når vi beregner variasjonen omkring middelet. Vi mener at man bør operere med et produksjonspotensiale som ligger mellom gitte konfidensgrenser. Dersom vi anvender 95 %

konfidengrense bør verdien for middelproduksjonen (produksjonspotensialet pr. 1983) ligge mellom 96 og 100 TWh.

Disse resultatene er fremkommet ved å studere et fåtall tidsserier. Det kan imidlertid være på sin plass å vurdere produksjonsseriene mere inngående. Til dette må vi analysere data fra flere meteorologiske og hydrologiske stasjoner. Vi bør også diskutere prinsippene ved dagens simuleringsmodeller for produksjonsberegninger. Det lave variasjonsmønstret er overraskende, og bør forklares bedre enn det tiden har tillatt. Hovedkonklusjonene om at datagrunnlaget virker pålitelig og simuleringsperiodene er tilfredsstillende vil en utvidet analyse neppe kunne rokke ved.

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