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Germany's Irrigation Sector under Conditions of Restricted Water Allocation

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1. Introduction

In his remarkable 5th N.D. Gulhati Memorial Lecture on the occasion of the 1993 ICID-Conference in The Hague (Netherlands) Marvin E. Jensen asked the question : "Is irrigated agriculture sustainable?" In answering his question he stated: "Because irrigation has been practiced at least 5.000 years in some regions, it can be sustained. Some projects will not be sustainable for want of renewable water supplies. From a global standpoint, the answer must be *yes*. Production of sufficient food for current and future populations requires irrigated agriculture. Globally it must be sustained, but not all existing irrigated areas can be sustained (Jensen, 1993)". Will irrigation in Europe, in Germany be sustained under conditions of economic pressure and of an increasing competition for natural resources?

It must be expected that the average profitability of agricultural and horticultural production in Germany is likely to decrease in real terms and that output prices will increase less than input prices. Furthermore, opposition to water use in agriculture is likely to increase. Will irrigated agriculture be able to survive under these conditions? The following paper intends to give some information on irrigated agriculture in Germany and to point out its problems.

2. Irrigated agriculture in Germany

2.1 Physical environment and history of irrigation in Germany

The Federal Republic of Germany has a population of about 80 million and an area of 356,853,950 square km. It is a densely populated country with a highly developed industrial and agricultural sector. The population of the F.R. of Germany has tripled in the past 100 years. The agricultural area in use per person was 0.78 hectares in 1883. It declined in the western part of the country to 0.29 ha in 1950 and 0.18 ha in 1991. After unification with the former communist German Democratic Republic the area used for agricultural purposes per capita increased to 0.35 ha. Towns and other residential areas, industry and transport take up 12.2% of the nations area.

Table 1: Climate and weather (long term average) in Germany

Place	Height above sea level in m	Air temperature in °C			Precipitation in mm	
		Jan.	July	Year	May-July	Year
Hamburg	6	0,4	16,4	8,4	212	744
Magdeburg	50	-0,6	18,1	9,0	175	521
Hanover	55	0,5	17,0	8,7	204	644
Lüdenscheid	444	-0,2	15,5	7,8	302	1204
Cologne	53	1,6	17,7	9,5	238	769
Cottbus	69	-0,9	18,4	8,8	193	573
Geisenheim	109	1,1	18,5	9,8	143	535
Würzburg	177	-0,3	18,2	9,0	179	597
Freudenstadt/ Black Forest	728	-1,7	14,9	6,5	374	1586
Munich	518	-1,7	17,3	7,9	363	948
Oberstdorf	815	-3,0	15,1	6,0	598	1834
Chemnitz	418	-1,6	16,3	7,5	257	726

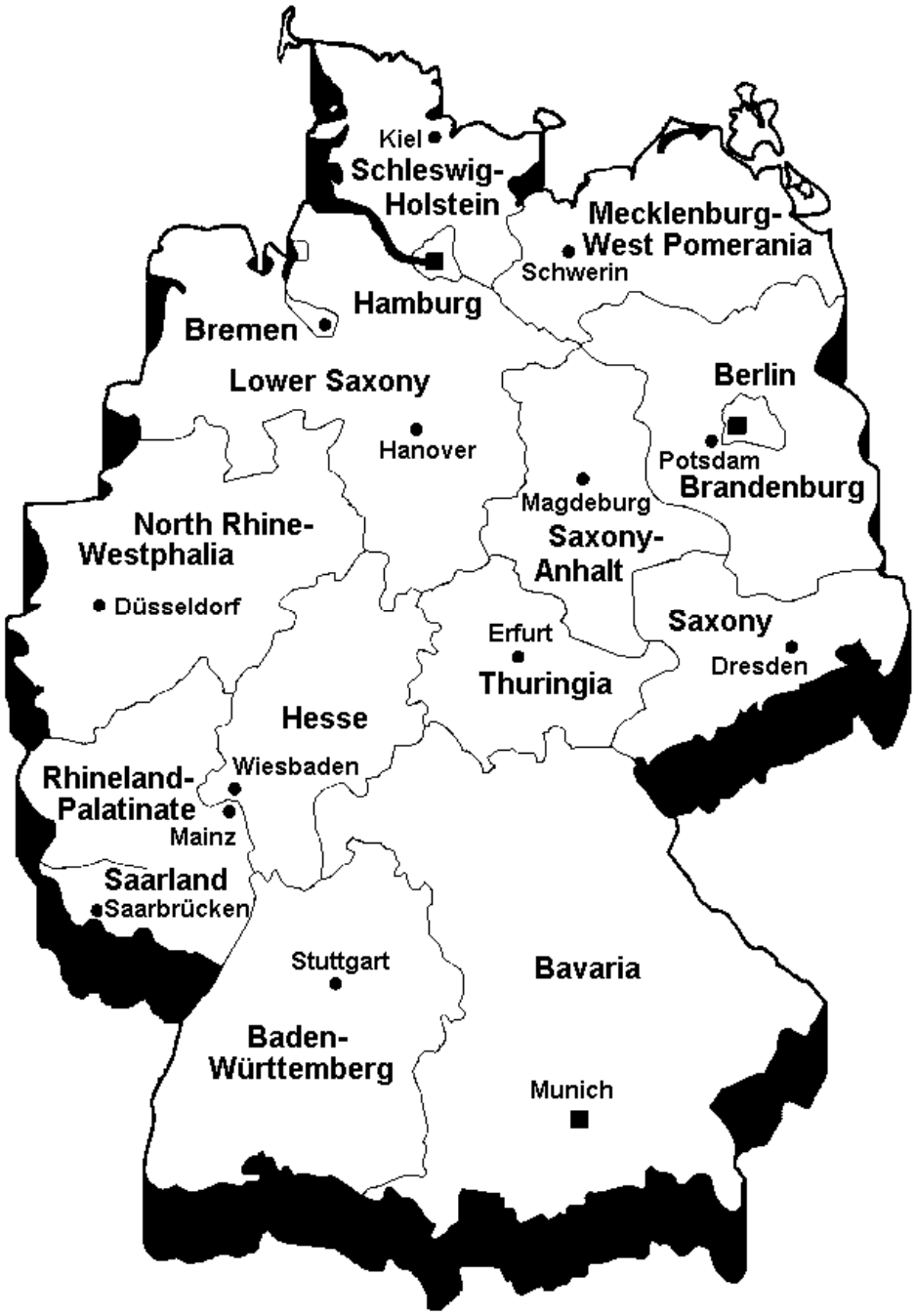


Figure. 1. The states of the Federal Republic of Germany

The Federal Republic of Germany is still a green country: 54.5% of the area is agricultural land and 29.1% are covered by forests. With 27.5% the proportion of forests in the new states is less than in the old states (29.8%), where there has also been more reafforestation over the past decades.

Despite of the decline in the percentage of the land used for agricultural purposes per inhabitant, agricultural production still provides 80% of the food consumed and as much as 92% when imported feed stuffs are considered. In 1991 the value of agricultural production of around 69 billion DM was higher than the turnover from the iron and steel producing industry (42 billion DM) and more than double of that of mining (32 billion DM).The relatively high degree of self sufficiency has only been possible through the increase of outputs in crop and animal production. For example during the pre-war period average potato yields per hectare reached 18.5 metric tons, in 1990 the average yield reached 31 metric tons per hectare. In maintaining such high yields in plant production it became increasingly necessary to optimize - besides other factors - the water supply of crops. Therefore, irrigation became an important production means in some agricultural areas of Germany.

There are big differences in precipitation between Western and Eastern Germany. From West to East Germany annual precipitation is decreasing. While there are 6% of the area in Western Germany receiving less than 600 mm/a, the latter holds true for 64% of Eastern Germany's land surface. The climatic water balance in central Eastern Germany during the growing season (April - September) is reaching - 116 to - 268 mm (Roth et al., 1991). Because of this irrigation is of even greater importance to agriculture in Eastern Germany. As shown in figure 2 a climatic water deficit prevails in many parts of Germany during the summertime.

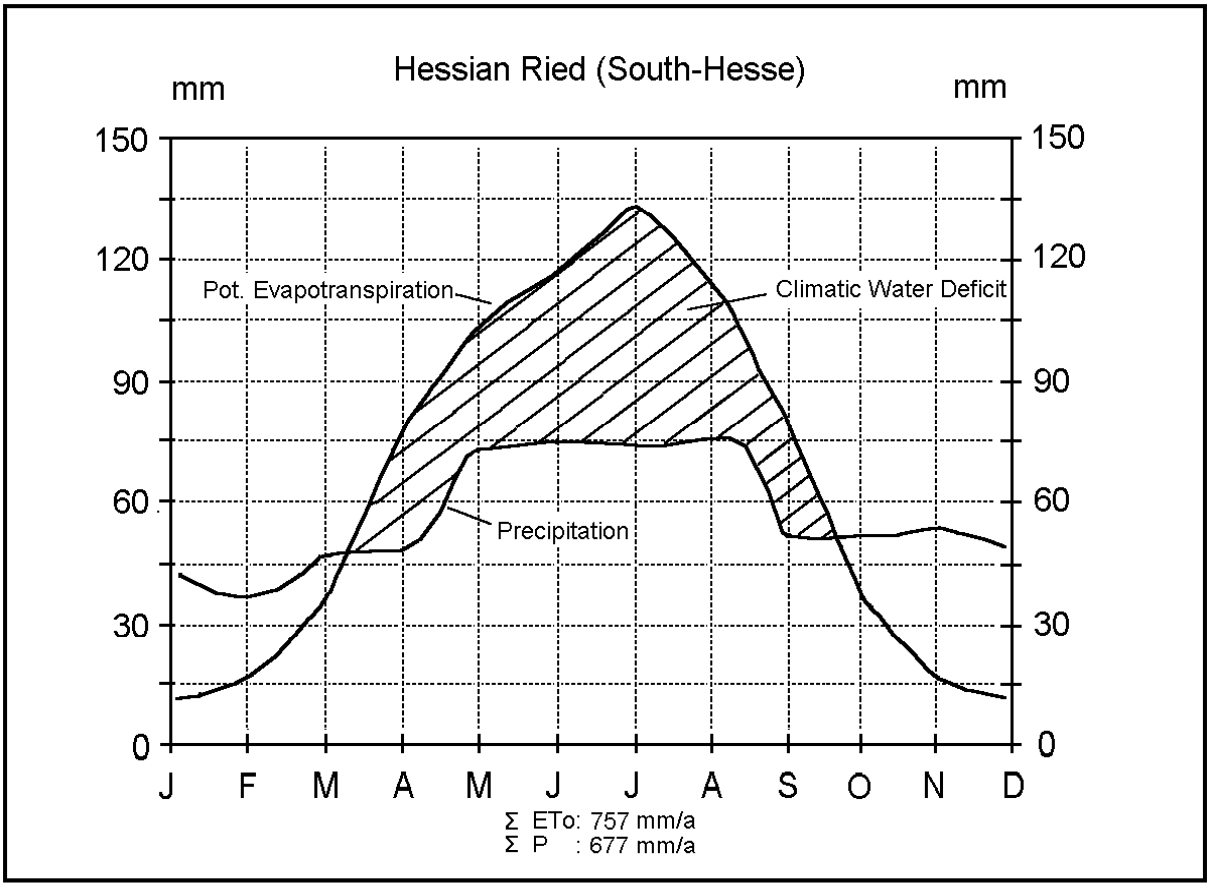


Figure 2: Climatic water balance of the irrigation area of the Hessian Ried south of Frankfurt.

Irrigation requirements depend upon crop, climate and soil type. The predominating soils in Germany are light sandy, shallow and stony moor land or peat soils of moderate or limited

productivity. The largest areas of soils of sandy origin are found in the glacier areas of northern and eastern Germany and in the river low lands in the southern regions These soils have poor water holding capacities and require more frequent replenishment. Due to the negative climatic water balance in many areas during the summer months, the majority of crops grown on these light soils experience moisture deficits in most years.

Irrigation of pastures was started in Germany more than 450 years ago. The first known regulation of the "Siegener Wiesenbau" dates back to 1539 (Heinemann, 1913). Large scale irrigation of field crops did not start before the beginning of this century. Due to the unfavourable topographic conditions and the supplemental character of irrigation surface irrigation methods could not be applied on arable land in Germany. This is why sprinkler irrigation was used in irrigation of field crops from the very beginning up to now. It developed from very simple irrigation equipment to modern irrigation machines todays .

Max Eyth, the founder of the German Agricultural Society, became one of the most determined individuals to indroduce sprinkler irrigation into German agriculture at the turn of the century (Wolff, 1988). At this time, the use of sprinkler irrigation was confined to a few, mostly large farms, although remarkable technical development in sprinkler irrigation equipment, promising results of experiments carried out by the Kaiser Wilhelm Institute in Bromberg, and encouraging experiences from agricultural practice already should have rendered a much greater acceptance of this technology. In fact, in pre-war Germany it was more often than not an "individual hobby", to use the apt description of Schonnopp (1969). However, neither the inventors of irrigation equipment nor the supporters of sprinkler irrigation were deterred by the reluctance of farmers to take up the new technique. On the contrary, reduced food production at the end of World War One and the general shortage of raw materials stimulated the inventors and supporters of irrigation. Shortly after 1918 and especially after World War Two, considerable technical developments took place in sprinkler irrigation technology as well as in German agriculture as a whole.

Despite the highly successful introduction of sprinkler irrigation in Germany during the last decades, there are problems especially in respect to the use of water resources. This paper will discuss these problems and show the solutions found so far.

2.2 Irrigated area and methods of irrigation in Germany

In the humid climate of the Federal Republic of Germany irrigation is generally practised supplementary except in the case of crops grown under permanent or temporary protection. The principal purpose of outdoor-irrigation in Germany is to increase crop yields, to secure a constant high level of yield and to protect crops, mainly orchards, from frost damage. Irrigation facilities are utilized to a varying degree from year to year, depending on the particular climatic conditions and on the kind of crop grown.

In the western part of Germany (the so called old states) there are about 400.000 hectares, or approx. 2.6% of the agricultural area in use, for which irrigation facilities are provided. This area is irrigated in most seasons, although in some years the quantity of water applied would be small. The major crops irrigated are sugar beets, potatoes and maize. Cereals and fodder crops are of lesser importance followed by pastures, fruit trees and vegetables taking up smaller areas. There are some irrigated areas where irrigation of vegetables is dominating, for instance in the Rhineland - Palatinate.

97% of the irrigated area in Western Germany is under sprinkler irrigation (Table 2). The remaining 3% are irrigated by gravity flow systems and a minor part by drip. Since turn of the century irrigation methods in Germany as a whole changed from the surface irrigation method, mostly used on pastures, to hand-move sprinkler irrigation, with quick-coupling pipes in the mid 1960´s. The next development stage brought about a change from sprinklers being directly mounted to the pipes towards those which were connected by hoses. The latter reduced the number of pipe-shifts three to four times, but still requiring considerable labour input. This method of sprinkler irrigation perished in most areas in western Germany up until the late 1970´s. The development of hose-reel irrigators started in the mid 1960's and by 1970 the first machines were available on a commercial scale, perfected under the rough operation conditions in the Braunschweig effluent disposal area. The hose-reel irrigator now has become universally adopted in most German irrigation areas. In the 1980´s investigations started to replace the gun sprinkler by a boom-sprinkler to improve uniformity of water application and to reduce energy requirements. More recent - but still rather academic - developments have been to investigate automatic irrigation systems like center pivots and lateral move systems. Dispite obvious advantages in water and labour requirements, drip/trickle irrigation has not developed to any extent except in vineyard and orchard irrigation or for irrigation of other high value crops.

Table 2: Development of land irrigated by different methods of water distribution in Western Germany from 1952 to 1994

Year	Total hectares irrigated	Hectares irrigated by	
		Sprinkler systems	Gravity flow systems
1952	201 141	31 453	169 688
1958	250 354	78 053	172 296
1969	232 240	168 279	63 961
1976	253 394	243 386	10 008
1982	319 914	311 468	8 446
1994	400 120	n.a.	n. a

In the eastern part of Germany, in the so called new states resembling the former German Democratic Republic, there have been about 520,000 ha, or approx. 8.4% of the agricultural area in use for which sprinkler irrigation facilities are still provided today. Up to the re-unification of Germany this area was irrigated in most seasons, some very intensively. The major crops irrigated by sprinkler irrigation were sugar beets, potatoes, fodder crops and cereals followed by vegetables and fruit trees. With the re-unification of Germany the economical situation in the eastern part of Germany has changed dramaticly. Caused by this change the economics of irrigating fodder crops and cereals became questionable, as well as the use of large scale sprinkler irrigation systems. In the years following re-unification the irrigated area declined rapidly; by now only about 131.000 ha being approx. 25% of the former irrigated area, remain to be irrigated in the eastern states each year.

In the eastern part of the country semi-portable sprinkler systems - and among them the well-known side roll sprinkler laterals (80%) - prevailed up to the re-unification followed by hand-move sprinkler irrigation systems (25 %). There were some centre pivot irrigation systems of the Russian made FREGAT-type in use since 1974 (6 %) and permanent irrigation systems accounted for 2 % of the sprinkler irrigated area in eastern Germany.

Table 3: Development of sprinkler irrigation area in Eastern Germany from 1960 - 1990

Year	Area irrigated by sprinkler irrigation systems in 1000 ha	% LA[x)]
1960	25	0,4
1970	168	2,7
1975	286	4,5
1980	412	6,6
1985	494	7,9
1989 (90)	520	8,4
[x)]LA = land used for a agricultural purposes (arable land and pastures)		

In areas of Eastern Germany with the water table being close to the soil surface during the wet months ground water regulation had been also used as a means of sub-irrigation. Approximately 590.000 ha of land are still equipped with facilities for ground water regulation (Riesner u. Tauschke, 1992).

Table 4: Sprinkler irrigation area in different Federal States of Germany in 1994

Federal State	Agricultural area in use (1,000 ha)	Area sprinkler irrigated (ha)	agricultural area in use (%
Bavaria	3.381,4	35.000	1,04
Baden-Württemberg	1.460,3	20.000	1,37
Berlin (West)	1,5	200	1,33
Brandenburg	1.298,4	20.000	1,54
Hessia	786,3	45.000	5,72
Mecklenburg-West Pommerania	1.313,2	12.500	0,95
Lower Saxony	2.714,1	233.500	8,60
North Rhine Westphalia	1.565,0	35.000	2,24
Rhineland Palatinate	714,3	25.800	3,61
Saarland	73,5	170	0,23
Saxony	898,1	26.600	2,96
Saxony-Anhalt	1.134,5	56.900	5,02
Schleswig-Holstein	1.055,7	5.450	5,16
Thuringia	788,5	15.000	1,90
Germany in total	17.184,8	531.120	3,09

Source: Roth et al., 1995.

According to a recent survey carried out by Roth et al. (1995) at present 531.120 ha or 3,09% of the agricultural area in use are irrigated by sprinklers in Germany. Table 4 shows the sprinkler irrigation area in the different federal states in 1994.

2.3 Irrigation water requirement, quantities of water applied and yield responses

The climatic water balance of one of Germanys typical irrigation areas is shown in Figure 2 and in two others figures in the Annex. The quantity of irrigation water required for crops in Germany is very small, in comparison with arid or semiarid regions. Often only 100 mm to 250 mm of irrigation are needed per annum; occasionally no irrigation is needed at all. Irrigation is required during sensitive plant stages for various crops as illustrated in Figure 3. More

information in respect to water requirements of agricultural crops in Germany is given by Roth (1991 a and 1991 b). The average annual irrigation water application is found in Table 5.

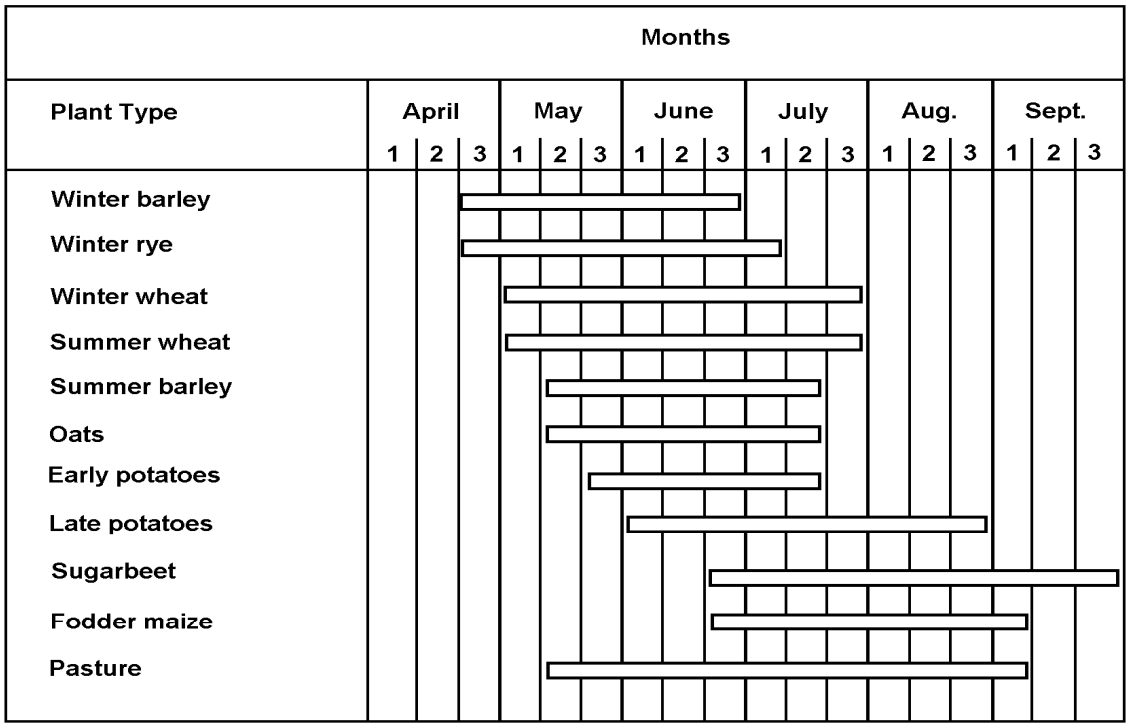


Figure 3: Periods when irrigation may be required for crops in Germany (Bramm, et al., 1979)

It is estimated that in Western Germany a total of 238,055,600 m^3 of water was applied to 319,914 hectares of irrigated land with an average of 750 m^3 /ha or 75 mm (1982 survey). The average amount applied per hectare, as reported in the 1976 survey, was 829 m^3 /ha and in the 1969, 1958, and 1952 surveys 3.063 m^3 /ha, 4.903 m^3 /ha and 5.631 m^3 /ha respectively. The above figures show that the amount of water applied has decreased considerably during the 30 years under study. This decrease of water application in irrigation is attributed to the dramatic change from surface to sprinkler irrigation, the latter with a much higher water application efficiency; and it was also effected by the shift from pasture to field crop irrigation.

It was estimated that in 1980 1,380 billion m^3/a of water were used for agricultural purposes in Eastern Germany; from which 1,185 billion m^3/a were used entirely for irrigation. Water withdrawn for irrigation purposes amounted to 14,9 % of the total withdrawal for all purposes.

Today, water application in sprinkler irrigation vary from 20 to 300 mm per year depending on the climatic conditions, the water holding capacity of the soil and the crop irrigated (Table 4). The quantity of water applied at each irrigation is more or less standard at 20 to 30 mm.

Table 5: Average annual irrigation water applied and yield increase with sprinkler irrigation in Western Germany

Crop	Irrigation water applied		Average yield increase range
	light soils mm year $^{-1}$	medium soils mm year^{-1}	tha^{-1}
Grain crops	30 - 60	20 - 40	0 - 1
Sugar beet	80 - 150	60 - 120	4 - 12
Early Potatoes	40 - 80	30 - 60	2 - 8
Late Potatoes	40 - 80	30 - 60	0 - 8
Maize	80 - 120	60 - 100	0.5 - 3.5
Vegetables	150 - 400	150 - 300	varying

The course of land development and irrigation in Northern Germany can be seen as an example of the stages of development of irrigated agriculture in Germany. The area south of Hamburg towards Celle and Hannover, called the "Lüneburger Heide", contained originally large areas of heath country. Until the second world war it was in large parts a remote and sandy waste land. In earlier times agricultural production was at a low level with farmers running sheep. With the introduction of sprinkler irrigation and the use of mineral fertilizers it became possible to raise the fertility and productivity of these poor soils. Development was spurred on by the partition of Germany after World War II when the majority of Germany's agricultural lands was lost . The second big change was the introduction of sugar-beets. Originally it was not thought to be possible to grow sugar-beets on these light sandy soils, but this proved to be incorrect when high rates of fertilizer were combined with irrigation to give continuity of crops and the certainty of achieving satisfactory yields. An example of yield response to irrigation is given in Figure 4.

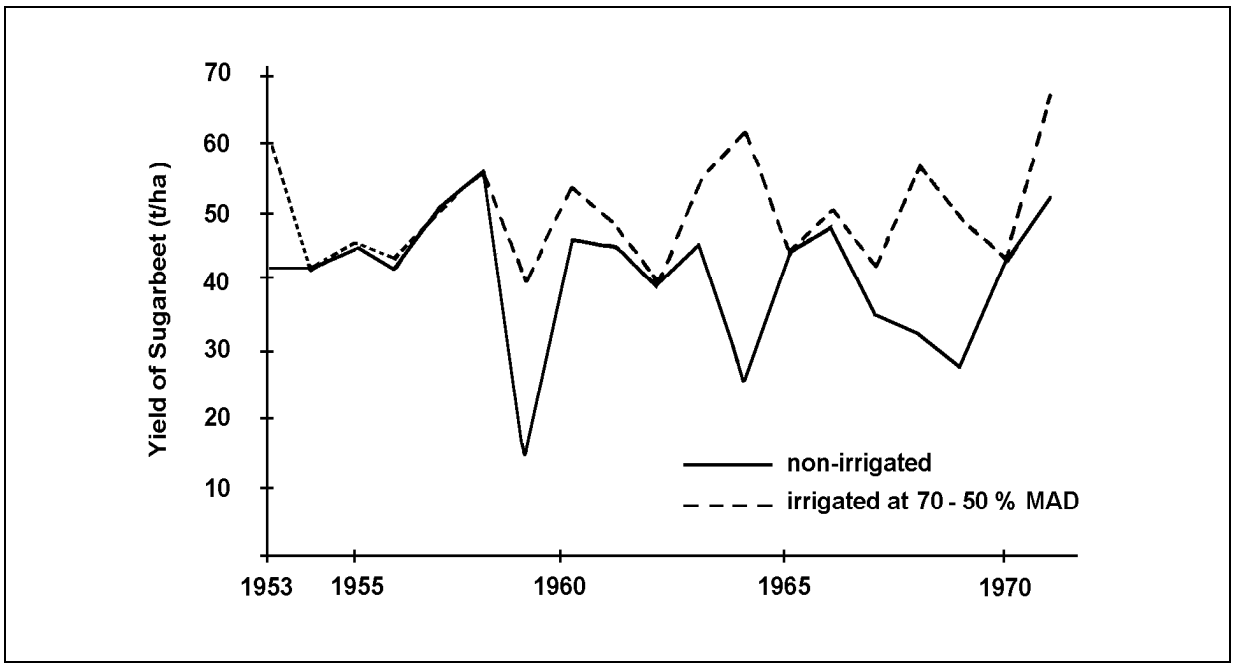


Figure 4: Yield response of sugar-beets to irrigation at management allowed water deficits (MAD) of 70 - 50% of available soil water, FAL Braunschweig - Völkenrode.

Table 6: Average yield increase (a) and yield response (b) from supplementary irrigation of crops grown on different soil types in Eastern Germany (1970/71 - 1985/87)

Crop	Soil type (Location)							
	loamy sand (Müncheberg)		loamy sand (Berge)		deep loess (Straußfurt)		shallow clay loess (Straußfurth)	
	a dt/ha	b kg/mm	a dt/ha	b kg/mm	a dt/ha	b kg/mm	a dt/ha	b kg/mm
	1		2		3		4	
Sugarbeet	96	71	94	74	84	88	140	102
Potatoes (second early and main crop)	111	97	136	127	121	100	138	152
Winter wheat	24,5	22,5	11,3	14,7	4,2	6,7	13,5	13,6
Sommer barley	20,0	25,0	8,8	14,7	3,5	8,3	12,7	18,4
Grass (Lolium multiflorum) (dry matter)	49,6	22,4	30,2[1)]	20,4	42,8	24,1	66,4	24,9

[1)] 1984-88

Extensive longterm experiments on sprinkler irrigation of different field crops have been carried out at different places in Germany. The Research Center Müncheberg of the former East German Academy of Agricultural Science (Kappes u. Schäfer, 1993) and the Federal Research Station for Agriculture in Braunschweig-Völkenrode were playing a leading role in these investigations. A summary of results from Northern Germany has been published by Bramm, Tries and Siegert (1984). Although the demand for irrigation on the lighter soils of Northern Germany was demonstrated by the longterm experiments, the authors point out that exact statements on the merits of irrigation can only be gained from an analysis of economics at the farm level because the internal utilisation of work and capital is a decisive factor for the efficiency of irrigation.

2.4 Economics of irrigation

An economic outlook on irrigation in Germany has to consider that a humid climate usually does not provide for a typical “irrigated agriculture“ like in the arid regions of the world. In terms of costs and revenues, temperate zone irrigation resembles only as much a regular production input as, for example, fertilizer or herbicides. Therefore, general trends in agricultural policy affect irrigated and rainfed farms alike - and these trends are not very promising. Further reductions of grain crop prices as well as quotas for sugar beets and milk can be expected by the year 2000, proving again that market deregulation is far from being installed. Such a scenario calls for further increases in farm size and drastic reductions in production costs, especially wages and machine costs. Right now almost none of the German farms operates in such a low cost range that it would survive the conditions predicted for the next millenium. On single operator managed farms of at least 250 ha, the upper limit of total investments in machinery is calculated to not exceed DM 2500 per ha (ACN, 1995). This means that in the future agricultural equipment will be replaced less frequently and at lower capital expense than in the past, creating a huge market for used machinery and for mechanisation consultancy services.

However, after thorough investigation of the financial situation on well-managed farms one has to admit that today agriculture - if carried out on large scale and under favourable natural conditions - could provide the farmer with as much an income as is earned by employees in other sectors of the economy. This is the challenge for many German farmers who have

survived the consolidation phase of the preceding decades, and it provides physically and psychologically the environment for few, but profound future investments into the farm enterprise hoping that agriculture might finally generate profits like in any other private business.

The supplementary nature of irrigation in Germany and the fact that crops with a relatively low market value are irrigated, coupled with the tense financial situation of most farmers, makes the economic evaluation of irrigation investment a critical matter. Supplemental irrigation reduces the risk of variations in crop yield and quality associated usually with rainfed farming; in addition, it enables farmers to grow crops which only thrive in a well managed soil water regime. The appraisal of irrigation investment and management involves the identification of the **extra** benefits and costs attributed to irrigation over those associated with non-irrigated agriculture. Considerable efforts are directed towards measuring the input implications of irrigation, both the investment required and the annual operational costs; but even more important is the response of crops to the irrigation water applied. The latter could vary considerably from year to year depending on management and weather conditions; on average gross water applications are 80-150 mm per year.

Ever since sprinkler irrigation was introduced into Germany the economic benefits of irrigation had been of major influence on the willingness of farmers

a) to invest in irrigation in general, and
b) to actually employ the equipment in a certain year.

As in most other European countries, irrigation in Germany is very capital intensive per unit of applied water, especially if investments in water storage structures are required. Costs vary due to:

- size, configuration and topography of irrigated fields
- type of and distance from the water source
- need for water storage
- type of irrigation technology
- daily and annual water requirements
- pumping lifts

The irrigation technology most used in Germany is the hose reel irrigation machine supplied with water by a mobile pump from shallow wells; in total about 13.000 units can be found on German farms. This assembly usually requires an investment of 60.000 DM per unit, resulting on average in 700 DM per ha farmed; even when buying old irrigation machinery these figures can only be reduced by 30 % (ACN, 1995). Regarding the above mentioned limit of capital investment, irrigation equipment could account for at least 20 % of allowed expenditures. However - management preferences, field size and soil conditions have a tremendous impact on the actual investment per unit of land. If one compares the economic situation of irrigation farming in Germany with that in other European countries, a great deal of similarities can be found, especially regarding cost factors and cost structures. For instance, in England costs of irrigation also vary considerably according to local conditions, making a generalization difficult; investments in hose reel irrigation systems are in the same range as in Germany, depending on system characteristics (ACN, 1995).

Irrigation farming in Germany - as anywhere else - faces the problem of increasing operating costs. Annual running costs on a typical German farm are around 6.50 DM per ha.mm, ranging from 4.50 DM per ha.mm without capital recovery to 12.50 DM per ha.mm under very

unfavourable water supply conditions. This must be paid for by revenues from crop yields above the rainfed average. For instance, on the basis of typical total application depths per crop and current crop prices at least 7 - 8 dt/ha of small grains, 30 - 40 dt/ha of potatoes and 60 - 70 dt/ha of sugarbeets have to be gained from irrigation, which is achieved easily in Germany in a dry year. Due to their low value fodder crops are usually not irrigated. Most profitable on the other hand is irrigating crops which are sold as fresh produce like vegetables, fruits and horticultural crops, because water not only determines yield but also product quality; therefore, this practice becomes increasingly popular and important, even on fairly small farms. However - as concerns the foreseeable future, the terms of trade in European agriculture are likely to continue to deteriorate due to rising costs and declining revenues. Those irrigated crops which render only a marginal profit will soon remain unirrigated, especially where the need for water storage creates exceptionally high irrigation costs.

2.5 Source of irrigation water

Due to the steady upward incline from the coastal regions of Northern Germany towards the Bavarian plateau and Alpine regions of the Southeast, the majority of Germany's rivers and their tributaries flow north and drain into the North Sea via the Rhine, Ems, Weser and Elbe. The Oder with its tributary Neiße, also flows north and drains into the Baltic Sea. The exception is the Donau which runs into the Black Sea and links Germany with Austria and South-eastern Europe. Lakes are found in regions covered by ice during the Ice Age as is in the North German Lowland and alpine fringe. Only the circular Eifel Lakes are of volcanic origin. In the Eifel, Sauerland, Harz Mountains and in the eastern part of the country reservoirs have been built to secure the water demand of larger cities and industries. In Eastern Germany, where 90% of the clear irrigation water comes from surface water sources, many of the smaller reservoirs have been built for irrigation purposes.

The total annual runoff from precipitation falling over the territory of West Germany is approximately 90 billion m^3. The flow of the rivers coming from East Germany and the neighbouring countries into West Germany amounts to approximately 80 billion m^3. About 110 mm of the precipitation - which is about 14% or 28 billion m^3 - percolate into the ground. Thereof 11 billion m^3 serve as recharge of the ground water storage. The total ground water storage is estimated to be 300 billion m^3. The total amount of water used in all sectors of West Germany's economy makes up approximately 14 billion m^3, including 238 million m^3 (1.7%) for irrigation purposes.

Table 7: Irrigation water use in West Germany by source, development of water consumption from 1952 to 1982

Water source	1952	1958	1969	1976	1982
			in Thousand m^3		
Surface Water	1,034,595	1,068,584	490,881	62,644	56,742
Ground Water	15,677	54,438	134,549	139,154	165,897
Sewage Water	82,416	103,385	85,987	8,336	15,061
Potable Water	--	1,146	--	--	355
Total	1,132,688	1,227,553	711,417	210,134	238,055

The average annual runoff in East Germany is about 17,7 billion m^3. It decreases to about 9 billion m^3 in dry years. The total amount of water used for all purposes before re-unification was 7,9 billion m^3, of wich approximately 15% have been used for irrigation purposes.

Of the 238 billion m^3 of water estimated to be used for irrigation in West Germany in 1982, 165,8 billion m^3 (67.7%) were pumped from wells, 56,7 billion m^3 (23.8%) came from surface sources and 15 billion m^3 (6.3%) was sewage water (table 7). Only 355.000 m^3 (0.15%) came from potable water sources (Wolff and Zöbisch, 1987/88).

Table 8: Water sources used for sprinkler irrigation in Germany

Federal States	Water used (in %) for sprinkler irrigation from		
	Ground water sources	Surface Water sources (Rivers, Lakes)	Reservoirs
Western states:			
Lower Saxony	90-95	5-10	-
North Rhine Westphalia	90	9	1
Bavaria	85	15	-
Hessia	80	20	-
Rhineland Palatinate (fruits)	70	30	-
Rhineland Palatinate (vegetables)	15	85	-
Schleswig-Holstein	50	42	8
Baden-Württemberg	50	40	10
Eastern states:			
Saxony-Anhalt	47	44	9
Brandenburg	20	70	10
Saxony	10	70	20
Mecklenburg West Pommerania	5-10	90-95	-
Thuringia	5	55	40

Source: Roth et al., 1995.

Table 8 gives an overview of the water sources used for (sprinkler) irrigation purposes in the different states of the Federal Republic of Germany. Note the above mentioned difference between the western and eastern states.

The data presented in table 7 shows that during the last 30 years in West Germany a dramatic change has taken place not only in respect to the amount of water used for irrigation but also in respect to source. In 1952 more than 90 per cent of the irrigation water came from surface sources and only 1.4 per cent from ground water sources. Thirty years later, in 1982 nearly 70 per cent of the irrigation water came from ground water sources and only 24 per cent from surface sources. The development of sprinkler irrigation in West Germany towards its present extent was only possible by using nearby water sources which in most cases are ground water. The use of surface water sources for irrigation of all irrigated land developed in West Germany during the last decades otherwise would have been only possible by installing extensive and costly distribution networks. This would have made sprinkler irrigation development unfeasible in many cases. Seventy percent of the irrigation systems, in East Germany are solely using clear water, which is mainly surface water with a small fraction of ground water. The percentage of irrigation systems waste utilizing water or liquid manure was up to the re-unification 15% each.

With the increasing water demand for industrial and municipal purposes in the sixties and seventies irrigated agriculture started facing problems to secure the necessary water supply. Since demand for water, especially high quality ground water has increased during the last decade, agricultural water users in Germany may be forced back to surface water sources for their irrigation water supply or may even have to give up irrigation.

2.6 Administration of irrigation works in Germany

The Federal Ministry of Food, Agriculture and Forestry is responsible for the control and supervision of irrigation and drainage development of national importance in the country. In most states (Länder) there are Ministries of Food, Agriculture and Forestry; in some states the name of the respective Ministry has changed, but the responsibilities are still more or less the same. These Ministries control and supervise important developments in their own states. They seek the approval of the Federal Ministry and increasingly of the European Union, too, if subsidies are needed. Each state is divided into regional districts (Regierungsbezirke), the administration of which is usually responsible for water allocations etc. In each regional district there are usually several public water engineering offices (Wasserwirtschaftsämter) responsible for the planning, implementation and maintenance of state water works, monitoring all water affairs within their area. They are also advising other institutions.

Large-scale irrigation development is mostly carried out and managed by Water and Land Management Associations formed by interested or benefiting land owners. These associations are corporate bodies, who manage themselves, but who are supervised in fundamental matters by their respective government. In Germany, there are at present more than 18,000 such associations, dealing - among other things - with water management, mainly in respect to drainage and maintenance of smaller water courses. The German water and land management associations are public law entities, as their tasks are those of a public authority. Membership is not limited to a geographical region but laid down in accordance with the associations functions and activities, although the majority of the tasks are related to specific geographical areas.

The roots of the German water and land management associations can be found in the 13th. century, when people started to work together for the purpose of flood protection. The first co-operatives dealing with the organisation and management of irrigation where established in the middle ages. The new law concerning water and land management associations (Gesetz über Wasser- und Bodenverbände), which has been enacted in 1991 and which replaced the regulations of 1937, is based on the historical experience of farmer self-managed water, drainage and irrigation works in Germany.

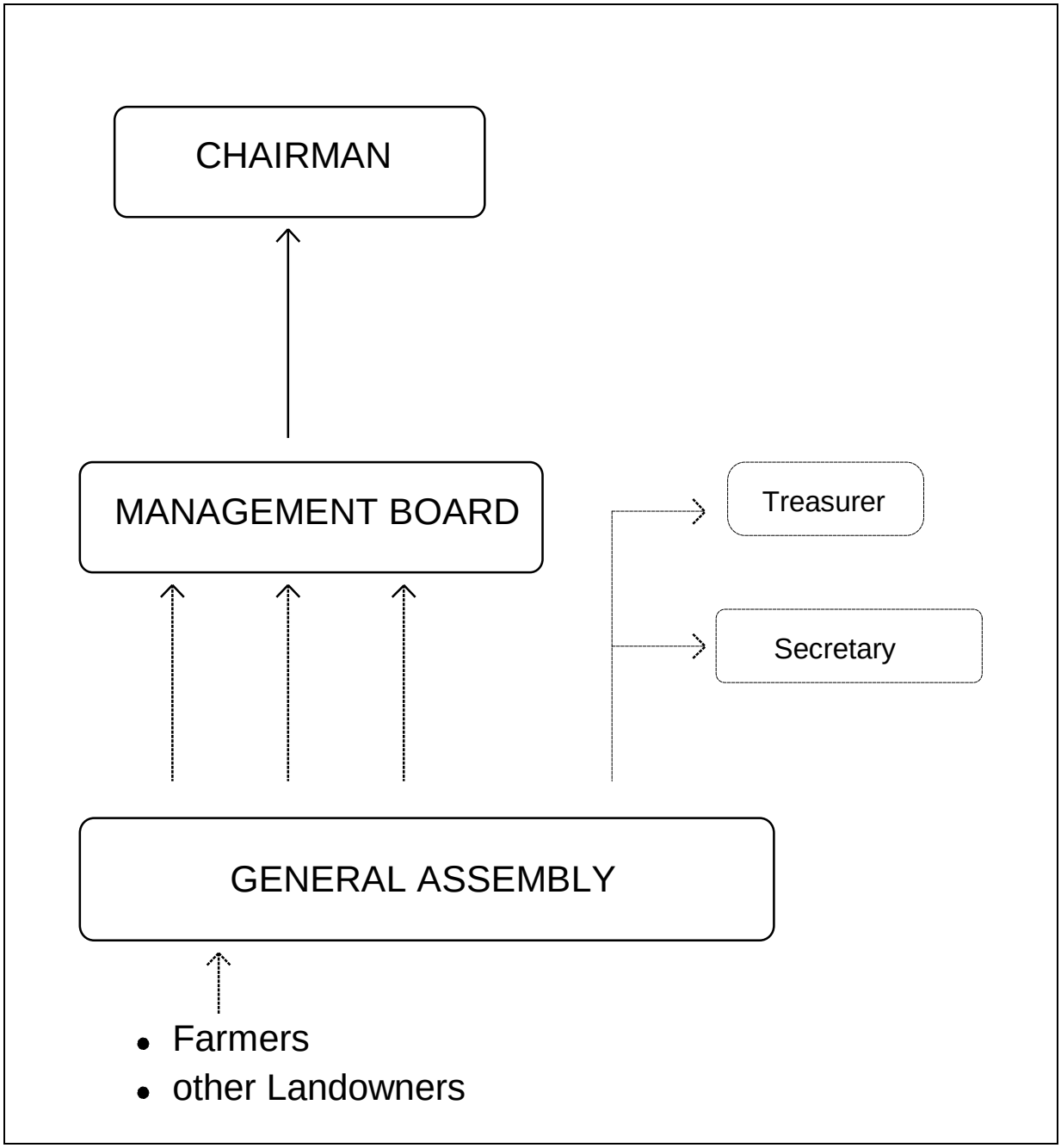


Figure 5: Organisational structure of a "Type A" Water and Land Management Association

A water and land management association may be established both at the instigation of parties or individuals affected and on government initiative proprio motu if it is a case of general public interest. Since, in many cases, it is necessary to have all parties concerned participate in the activities, it is possible, under certain conditions, to force them into compulsory membership if they do not join voluntarily. As far as irrigation associations are concerned the membership is on a voluntarily basis. In accordance with the law, membership in an association is open to any person - private or legal - who is in any way related to the activities of that association. This is why the law also allows local government bodies and other public law cooperations to become a member in an association. In addition, the supervisory authority may, on a case-by-case basis, extend membership to include for example organizations dealing with nature conservation or landscape issues (Winzek, 1993). In the field of irrigation this is

only the case if waste or sewage water is used as water source. The Sewage Water Association of Braunschweig is such an example. Besides the farmers using the sewage water for irrigation, the city of Braunschweig and the smaller cities of the area contributing to the sewage water supply are all members of this association. The relatively wide spectrum of member interests provides an opportunity for all parties to participate in the activities of an association.

In irrigation farming the membership is always linked to the land and not to the irrigator as a person. In order to guarantee a high degree of continuity in the work of the associations it is usually very difficult to withdraw membership from the association. Even if a plot changes hands the new owner is obliged to maintain membership and his contribution to the association.

In accordance with the German understanding of democracy, the principle of self-administration is given priority, and it is only replaced by government action or intervention in exceptional cases. Self-administration is represented and practiced by the general assembly of the individual association. The general assembly is constituted by all members. Statute settling tasks, contributions of the members to the association, periods of installation of the board and chairman as well as other organizational matters are established by the general assembly. The organisational structure of a German water and land management association is shown in Figures 5 and 6. The organisational structure shown in Figure 5 applies to smaller associations while the one in Figure 6 shows the setup of bigger associations. Self-administration is represented and practiced by the general assembly, in which all members of the association participate and have the right to vote, as well as by the management board and by the chairman. Both the management board and the chairman are elected by the general assembly.

The financial basis of an association is its membership fee, which has to be paid as public charges. The level of fees depends on the amount of funds needed to fulfill the association's tasks, and on the costs of services rendered by the association on behalf of its members.

The Water Management Association Law makes water and land management associations responsible for a variety of tasks of water and land management, which go beyond the mere protection of resources. The Law deliberately follows the tradition of water management association activities of the past, when the protection of resources played a relatively minor role. Today, resource protection activities have high priority in the work of water management associations (Winzek, 1993).

The activities listed in Art. 2 of the Law are mainly concerned with water management, whether the sources are to be surface or ground water. In accordance with this Article, water and land management associations may undertake comprehensive engineering and maintenance measures. They may act as water managers or consumers if they withdraw, supply or use water for drinking, agricultural or industrial purposes. They even may treat waste water in order to improve the quality of resources. The Law thus gives associations extensive scope for influencing water resources in general. The irrigation associations in Germany are all working under this regulation.

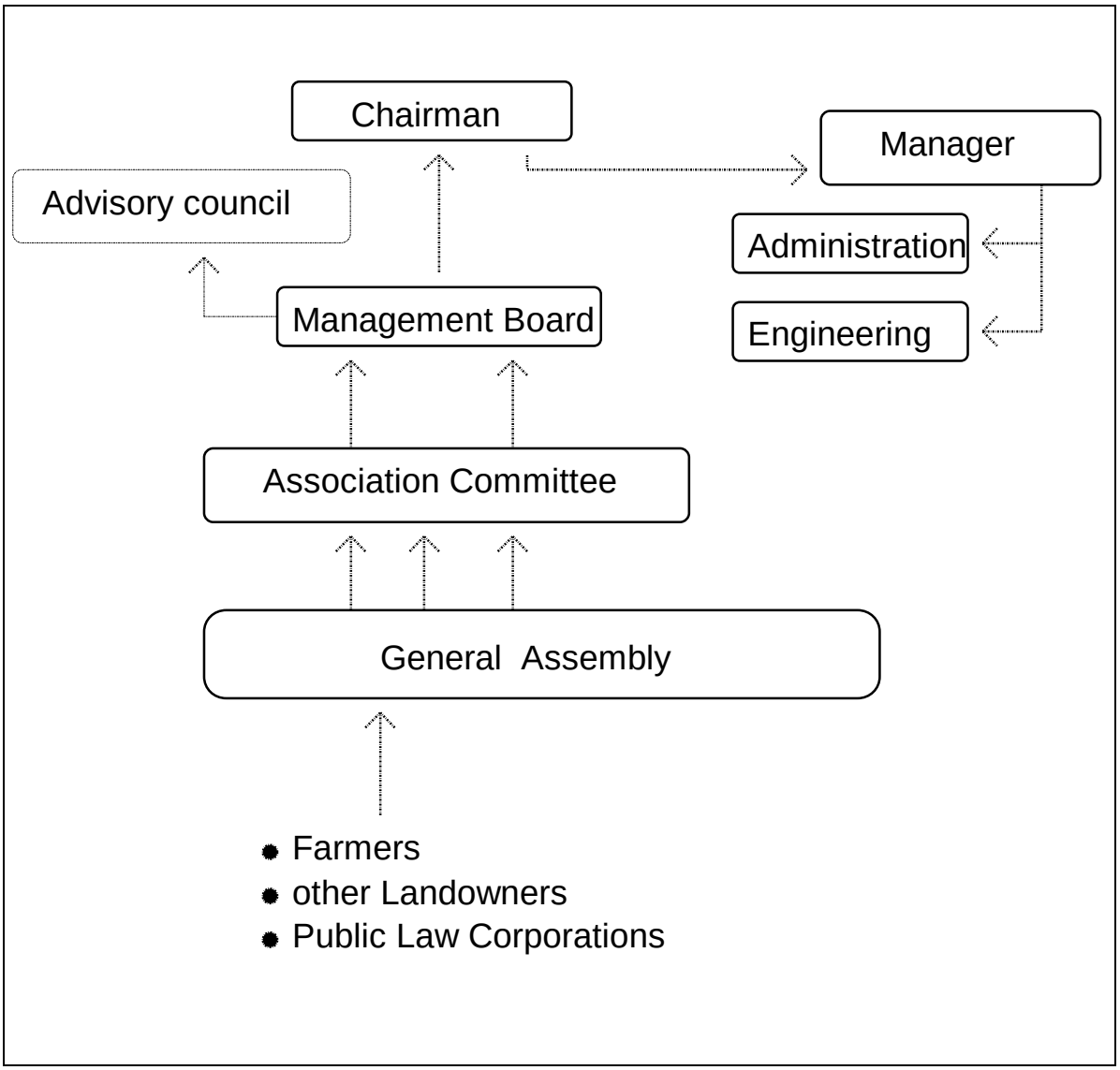


Figure 6: Organisational structure of a "Type B" Water and Land Management Association

The law does not contain a definition or detailed description of such activities and their extent. Instead, the rules governing the type and scope of tasks are found in the relevant water management and nature conservation legislation at the national or state (Länder) level.

The experience gained in water resource management in Germany shows that the system of "Water and Land Management Associations" provides an excellent tool of resource conservation. In the field of irrigation the management, water allocation is carried out quite successfully by irrigation associations. Similar structures exist for the management of other resources like soil conservation, environmental protection and landscape management. Often these tasks are also carried out by the above-mentioned associations.

2.7 Supporting services

2.7.1 General official supporting service

Under the pressure of food scarcity at the end of Word War II and the large number of Germans who where forced to leave the eastern provinces and who had to be settled in the central and western part of the country, agriculture was supported in order to raise food production. Later when the problem of food scarcity had been solved special supporting programmes were started to raise and secure farmer incomes as well as to help farmers getting prepared for the integration into the European Common Market. Besides other measures, at every above mentioned stage the support of irrigation, drainage and other amelioration played an important role. These government supporting activities came more or less to an end during the last decade, especially since overproduction became a problem within the European Union. Today the federal government and the state governments are still supporting irrigated agriculture in Germany, but now mainly in respect to reaching sustainability in the use of natural resources (saving of water and energy prevention of water pollution etc.). The irrigation scheduling advisory service is the most advanced supporting service offered to German irrigation farmers. Besides this service, German irrigation farmers may get advise in technical and economic matters from different state and private agricultural advisory services.

2.7.2 Irrigation scheduling advisory service

In Germany regional services for irrigation requirements are highly developed. They involve the Central German Weather Bureau (Deutscher Wetterdienst), especially the agrometeorological department including their outstations as well as the local organisations and advisers in each states Ministry of Agriculture for their implementation. Irrigation scheduling is based on real time estimates of the soil water balance and uses a considerable background of empirical experiments and experience.

This experimental base is continually being upgraded by field experiments carried out in the most important irrigation areas. The irrigation advice is based upon the water stored within the 0 - 60 cm depth of soil. This depth of soil, which is important in the plant water balance has been standardised for all crops in all areas of Germany despite the fact that obvious differences must occur. In some areas a soil depth from 0 - 90 cm is additionally used as a basis for irrigation during the later part of the season. The simplification is reasonable because the major crops which are irrigated are field crops like sugar-beets, potatoes and cereals, while fruits, vegetables and vines are relatively unimportant in the irrigation context. The estimations of crop water requirements are mainly based on several formulas that are attributed to Haude. The latter is widely used in West Germany, while in East Germany the formula of Turc was preferred. The evaporimeter used extensively in West Germany is of the porous-plate type developed by Czeratzki.

Two examples of the work of the irrigation advisory services are given below.

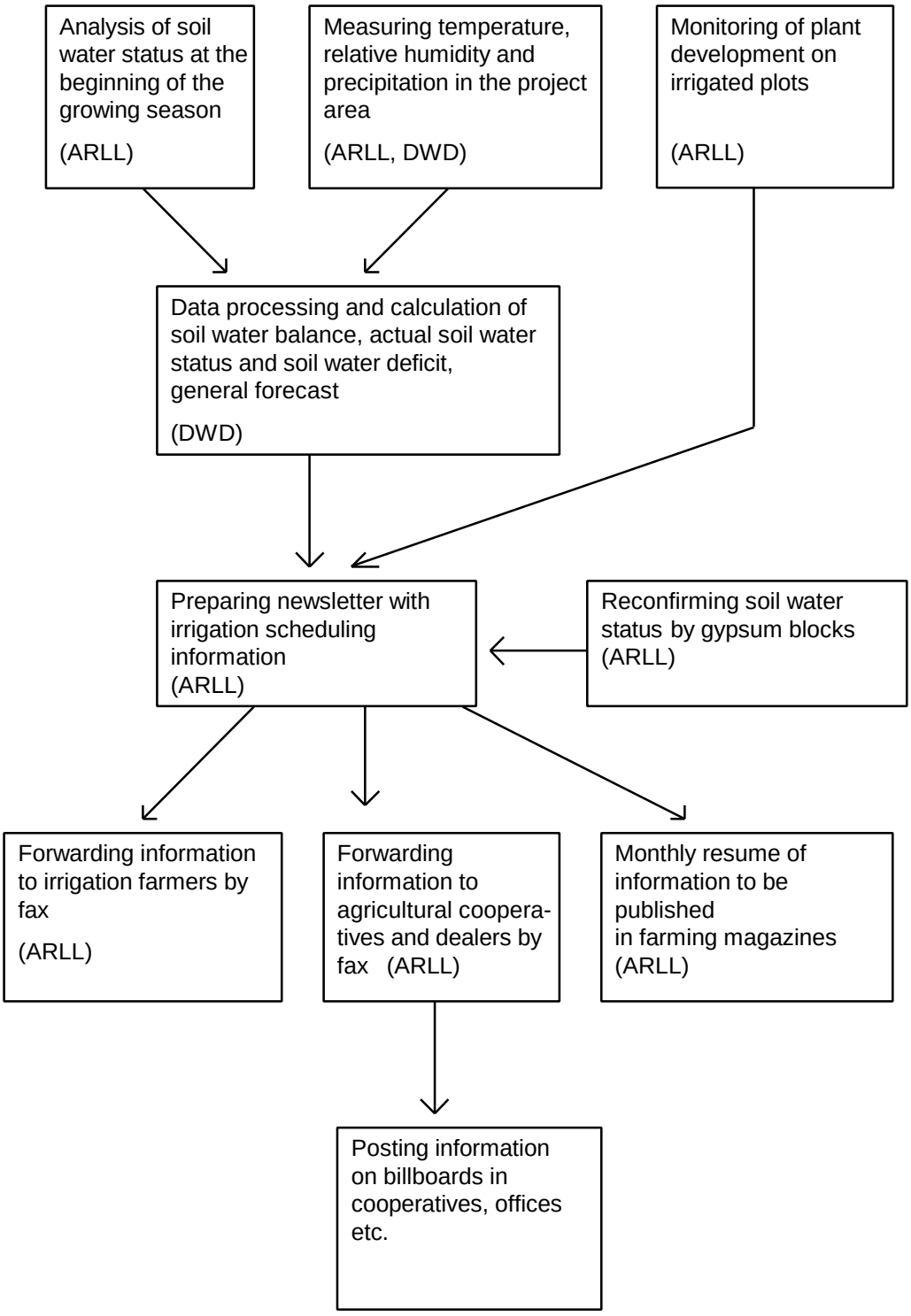
(a) Irrigation scheduling advisory service in Lower Saxony.
An officer at the agrometeorological research station of the German Weather Bureau at Braunschweig - Völkenrode in association with an officer of the Sprinkler Irrigation Working Group of the Sprinkler Irrigation Federation at Hanover inform on the actual soil water status each week. In general, the officer of the Working Group collects information from regional agricultural advisers and from experiment stations while the German Weather Bureau expert collects information from his weather recording stations.

The system could be roughly described as follows: Each Tuesday a large number of local weather observers, some of whom have been on duty for over 30 years, send a postcard to the officer. This postcard gives information of different kinds: Either rainfall and temperature are recorded or rainfall plus actual evaporation from the ceramic-disc-evaporimeter. By using the formula of Haude the officer calculates the evaporation of the past week. In addition there are over 15 sites where gravimetric soil moisture sensing is performed in a variety of crops. Four or five samples down to a depth of 60 cm are taken at each site and for each 10 cm depth the moisture content is converted to an equivalent depth of water. These are used to reconfirm the estimate of evapotranspiration based on evaporation. All the information is received on Wednesday. On Thursday the officer confers with his corresponding colleague in the Sprinkler Irrigation Working Group and they decide on the content of the weekly leaflet. The leaflet is printed and posted, or sent by fax so that the information is available to farmers latest on Friday. The circular is distributed directly to over 500 addresses who may be farmers, chairmans of irrigation associations, regional officers of the Chambers of Agriculture, agricultural advisory officers, or experts consulted by groups of farmers. The leaflet is widely spread and in addition the information becames part of the agricultural weather forecast of the local radio stations and the telephone services. The irrigation advice based on the calculated water balance is calculated to prevent the soil moisture content from dropping below 40% of the moisture holding capacity in the 0 - 60 cm depth. The maximum moisture deficit depends on the soil "point score" as described above.

(b) Irrigation scheduling advisory service Hessisches Ried

A regional officer employed by the Ministry of Agriculture of the State of Hesse works in close cooperation with scientists in the central office of the German Weather Bureau at Offenbach. This regional officer is specialised in irrigation scheduling advice to irrigation associations in the irrigation area "Hessisches Ried", south of Frankfurt. The system used is as follows (figure 7):

At the end of the winter the officer selects 20 sites in order to cover the following crops: Winter cereals, potatoes, sugar-beets and maize. At each site he takes five or six soil samples to a depth of 60 cm or 90 cm. Therefore he is able to determine the soil water stored up to this depth at the beginning of the growing season. These values are checked against the water holding capacity calculated from wilting point and field capacity analysis in the laboratory. Thereafter evapotranspiration is estimated each week by using temperature and humidity measurements. The crop water use per week is calculated in cooperation with the German Weather Bureau in Offenbach by using Haude´s formula. With this information and rainfall data they are able to determine the actual and seasonal soil water balance for each area and each crop. The officer of the Ministry receives support from farmers who provide data on quantities of irrigation water applied. He then calculates the quantity of irrigation water which is now required. In the early days these calculations were checked by gravimetric measurements of soil moisture every three weeks, but after some years of testing it proved to be unnecessary. In recent years the gypsem block method has been used instead quite successfully. Vegetable irrigation is considered difficult to schedule. Therefore evapotranspiration is calculated by using Penman's formula (Lorenz, 1992). This irrigation advisory service has been performed for twenty years. The information contained in a newsletter is sent out two times a week (Tuesday and Friday) usually via fax to about 550 people. It is also incorporated in the Weather Bureau's telephone advisory network.



ARLL = Ministry of Agriculture (Local Office)

DWD = German Weather Bureau

Figure 7: Irrigation advisory service "Hessisches Ried", Germany

3. The competition for natural resources

In all highly industrialised countries and many developing countries as well there is a strong and increasing competition for natural resources. The competition for water resources in Germany is between agricultural and urban users, the users of water for navigation canals and rivers and for hydroelectric power. In addition, over the past three decades the values placed on various uses of water have changed. The urbanized Germany not only demands water for new municipal and industrial uses, but also it needs to ensure environmental stewardship. Today the public is becoming increasingly aware of the value of free-flowing rivers, natural springs and lakes, wetlands etc. As these resources - being a fish and wildlife habitat, of great aesthetics, and providing outdoor recreation opportunities - become scarcer, the demand to preserve them rises. The relationship between water quantity and quality, which has long been ignored in Germany as well as in other countries, is now also a significant concern. These changing demands for water are leading to a strong competition for water resources and, at least regionally, place a burden upon the primary water user - irrigated agriculture.

One example of an existing water management problem is the competition for water in canals. Where fluctuations of the canal water level due to the operations of locks and weirs led to changes in groundwater levels in the surrounding areas, a compensation for the lowering of the water table was paid to farmers. This had occurred and is still the case in some parts of northern Germany. Elsewhere the water taken from existing irrigation supplies to maintain river and canal water levels for navigation had to be replaced from other water sources. A further example exists north of the city of Hanover, where a competition between the municipality and the farmers for groundwater resources has developed: There groundwater is held in a sandy aquifer refilled by vertical recharge. Previously the groundwater was close to the surface in some areas and drainage was necessary before the water table declined by water extraction for agricultural irrigation and municipal use. After some 30 years of litigation a compromise has been reached whereby the city is compensating farmers for reduced water supplies and increased pumping costs. The latter arises from the necessity to irrigate more frequently and from increased pumping lifts.

A similar situation occurred near the city of Darmstadt south of Frankfurt, in an area called "Hessisches Ried", where several irrigation associations have developed water sources for irrigation. The groundwater in this area is of better quality than from the river Rhine nearby. With the increasing urbanization of the so called Rhine-Main Area the water demand for municipal and industrial uses has increased. The population increases at a rate of 2% per annum or 150.000 people per year. At the same time, the recharge of groundwater decreases, because the sealing of the soil surface by extraordinary municipal, industrial and road network expansion (the "paved paradise") continues to spread. Recoverable groundwater resources are estimated to be 378 million m^3/a in a normal year and 370 million m^3/a in a dry year. The domestic demand, being 288 million m^3/a together with, the agricultural and industrial demand amount to an average of 99 million m^3/a. For irrigation purposes approximately 46 million m^3/a are used. This leads to a deficit of 9 million m^3/a, and a rapid depletion of groundwater resources, as shown by declining groundwater tables and land surface subsidence (Lehr, 1992). After many years of discussion a solution was found during the eighties. There is now a trading in water between the irrigation associations and the water works: Water is taken from the Rhine and used for recharging the aquifer and for irrigation after purification. The groundwater itself now serves only in part as irrigation water, whereas large quantities are substracted for domestic water supplies. From an economics point of view the solution found seems to be questionable, since the purification of the Rhine water is quite an expensive undertaking. The irrigation water is therefore highly subsidized.

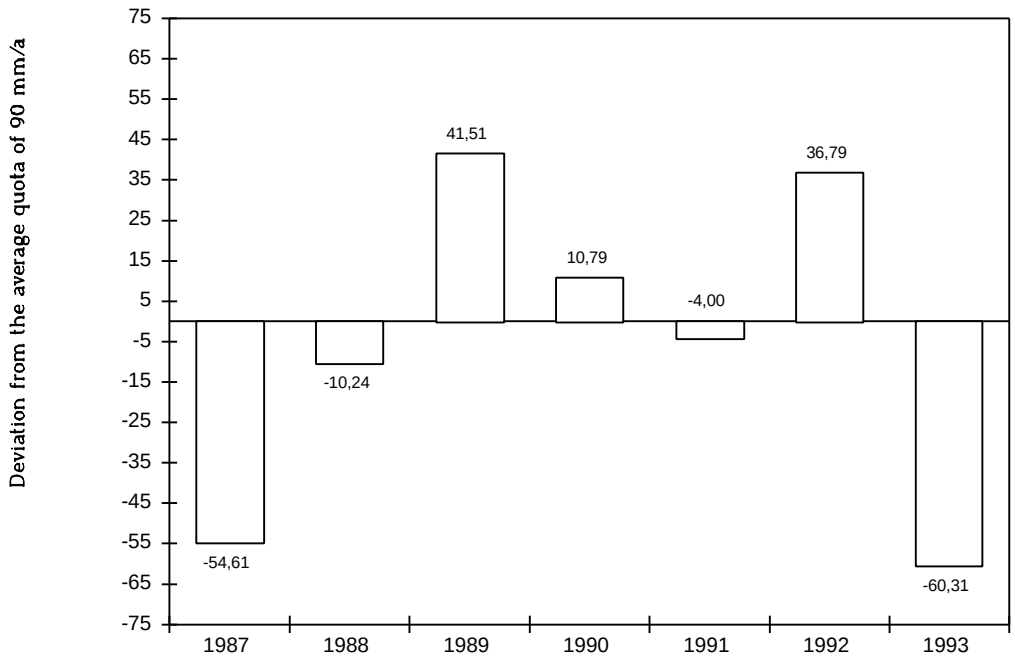
While most of the measures mentioned above were more or less in favour of irrigated agriculture, an increasing public and environmental opposition in respect to the use of high-quality groundwater for irrigation purposes was noticeable during the last decade . Also discussion continue in respect to the effects agriculture has on the environment in general, especially on the quantity and quality of ground and surface water sources, especially in respect to nitrate and biozide contamination. To correct and to prevent negative effects, the federal and state governments introduced special measures during the last two decades. The introduction of the so-called "Wasserpfennig" a special water fee in the order of 2% of total water costs, was one of them.

4. Effects of a changing water policy

Because of water scarcity in many of the urban and periurban areas of Germany, water is increasingly transferred from rural to urban areas. Since water or a water source is a public property, the state governments decide on the basis of the existing legal framework, who may substract at which site how much of a water source. As long as there was plenty of water available, permissious to withdraw water could easily be obtained. Very often this permission was unrestricted in time and quantity. As good quality water became scarce new procedures were introduced, especially during the present last decade. Water allocation is now restricted in quantity over a certain period of time, as an example from Lower Saxony explains.

The example concerns the Irrigation Association Güstau. The village Güstau is situated close to the city of Uelzen in northern Germany. Six farmers of this village belong to the irrigation association with an irrigation area of 276 ha. Because of the climatic conditions of the area it was calculated by the state water authority that on average 90 mm of supplemental irrigation water have to be applied per annum. The association obtained in 1986 a permission to withdraw water form the ground water aquifer below the village area 248,436 m^3/a or 1,739,052 m^3 over a period of seven years. Every pump and every hose-reel irrigation machine, which is common in the area, had to be equipped with a water meter, and the irrigation association was made responsible for controlling the water use of each individual member reading water meters and collecting water fees. The irrigation association is free to decide how much water to use during a year, but they have to make sure that altogether not more water than allocated for the time period of seven years is used. Figure 8 shows the water use over the period 1986 - 93. After a time period of seven years the association has to apply for a renewal of the permission. At the moment there are discussions whether in future water allocation should be based on an average applied depth of 80 mm/a instead of 90 mm/a.

The water fees collected by the association are transferred to a special fund and are used for water related environmental activities. Municipal and industrial water users also have to pay into this fund according to the amount of water used. For example, - including the maintenance of water ways and bodies, the prevention and/or reduction of water pollution are activities financed out of this fund.



Year	1987	1988	1989	1990	1991	1992	1993	Average/a
Actual applied depth (mm)	35,39	79,76	131,51	100,79	86,00	126,79	29,69	84,28

Figure 8: Actual water use by the Irrigation Association Güstau over the time period 1986 - 1993 in relation to the average allowed quota of 90 mm/a.

Water policy in West and East Germany was in practice up to the seventies mainly supply oriented. The responsible authorities were always trying to optimize the supply of water in order to meet the demands of the different users. The supplyside approach is according to FAO (1994) structure oriented; investments in water projects are combined with engineering and technical expertise to capture, store and deliver water and to make systems operate effectively. The supply side focuses on providing water and related services. When it became clear that good quality water was not an inexhaustible resource, water policy started to change slowly. A demand cutting water policy developed, forcing the different water users to implement water conservation measures through an increasing restriction of water allocations and the introduction of water charges. In some areas a successful cutback in water demand has been reported on account of these measures. For example in the district of Darmstadt, south of Frankfurt, the amount of water used was cut in the period 1991 - 93 by 22 Mio. m^3/a or by 7,5% that is from 292 to approx. 270 Mio m^3/a.

In Germany like in many parts of the world, policy-makers are increasingly emphasizing non-structural approaches to water management. According to FAO (1994) a non-structural approach encompasses demand management, scientific research, education and persuasion to coordinate how humans use water. These demand-side policies attempt to address the human causes of water problems such as water quality degradation, over exploitation of aquifers and the decreasing availability of water flows to meet non consumptive water uses (hydroelectric power, pollution assimilation, fish and wildlife habitats, outdoor recreation).

5. Lessons learned

The lessons which can be taken from the German irrigation sector experience can be grouped into two categories. The first of these comprises technical and farm water management issues. The second relates to policy and institutional issues.

Technical and water management issues:

1. The wastage of water can be reduced by improving irrigation technologies. For the successful uptake of modern irrigation there must be significant physical and agricultural advantages for using it, good market conditions, and considerable financial incentives for irrigation farmers.

2. Modern irrigation technology is not a panacea but it can play an important role in water conservation. The challenge is first to know when it is best to use modern irrigation systems, then to select the one which optimal fits and formulate the necessary institutional environment and supporting structures for successful operation when and where they are appropriate.

3. To make the best out of modern irrigation systems an advanced water management at the farm level is necessary. In order to accomplish this it is necessary to help farmers decide what crops, when to irrigate, how much to apply and how to prevent environmental degradation, especially in respect to soil and water resources. This of course involves both research and extension.

4. To accomplish water conservation measures a locally appropriate water allocation system with volumetric measurement and payment at some level is essential.

Policy and institutional issues:

1. The irrigation sector world-wide has to recognize that economic structures are dynamic and not static. The economics of Germany for example have undergone considerable change in the last decades. In connection with this change agriculture is loosing its leading role in economic development and this is, besides other things, effecting the allocation of water resources between agriculture and other users.

2. Because of the growing competition for ever-scarcer water resources governments, and water authorities are forced to change water polices. Objectives of the new policies are "demand - decreasing" and "demand -shifting".

3. The formulation of new water policy objectives is influenced by the guiding principles from the Dublin Conference on Water and Environment, held in January 1992. Among other things it was stated that "water has an economic value in all its competing uses and should be recognized as an economic good". Agriculture will not get water any more free of charge. Farmers will have to pay for the water and costs will be increasing steadily over the years to come.

4. There will be a reduction of the role of governments in rural water projects and an increasing importance of local user groups. Experience in Germany shows that an important solution to water related problems is to give users the responsibility for developing and managing the water resource. This requires that farmers become properly organized in water user associations able to discharge their new responsibilities, and that they have security of tenure to the land they farm and irrigate.

5. Farmer managed irrigation systems can only be successful, if the legal, financial and administrative conditions are supportive. A strong legal basis for water user organisations has to be provided. The mandate has to include financial autonomy for the managing entity. A fair and accessible professional auditing system has to be created and its use by the managing organizations mandated. The creation or improvement of an effective water rights administration to manage the water sector in general and the rural water sector in particular is essential.

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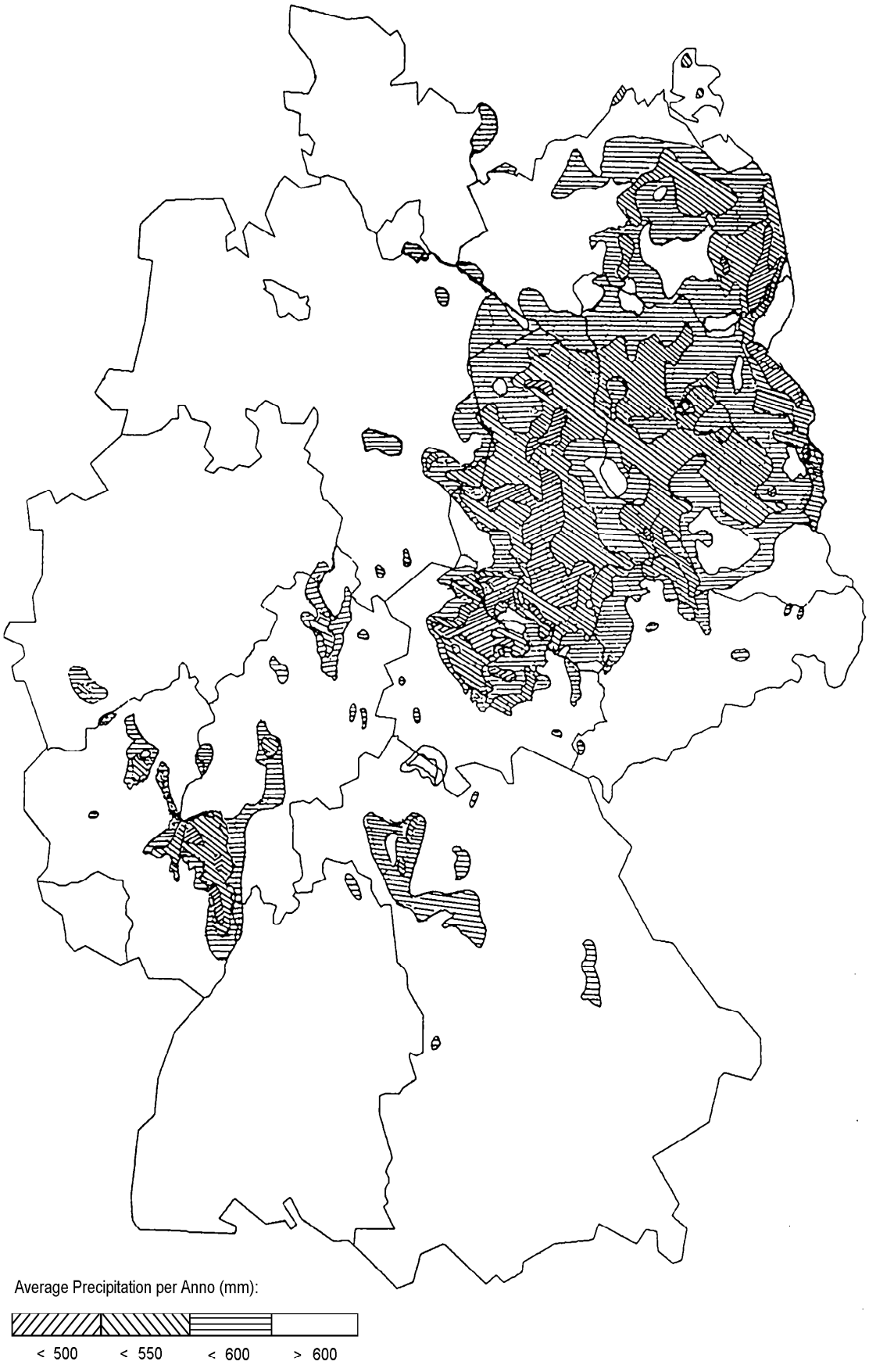
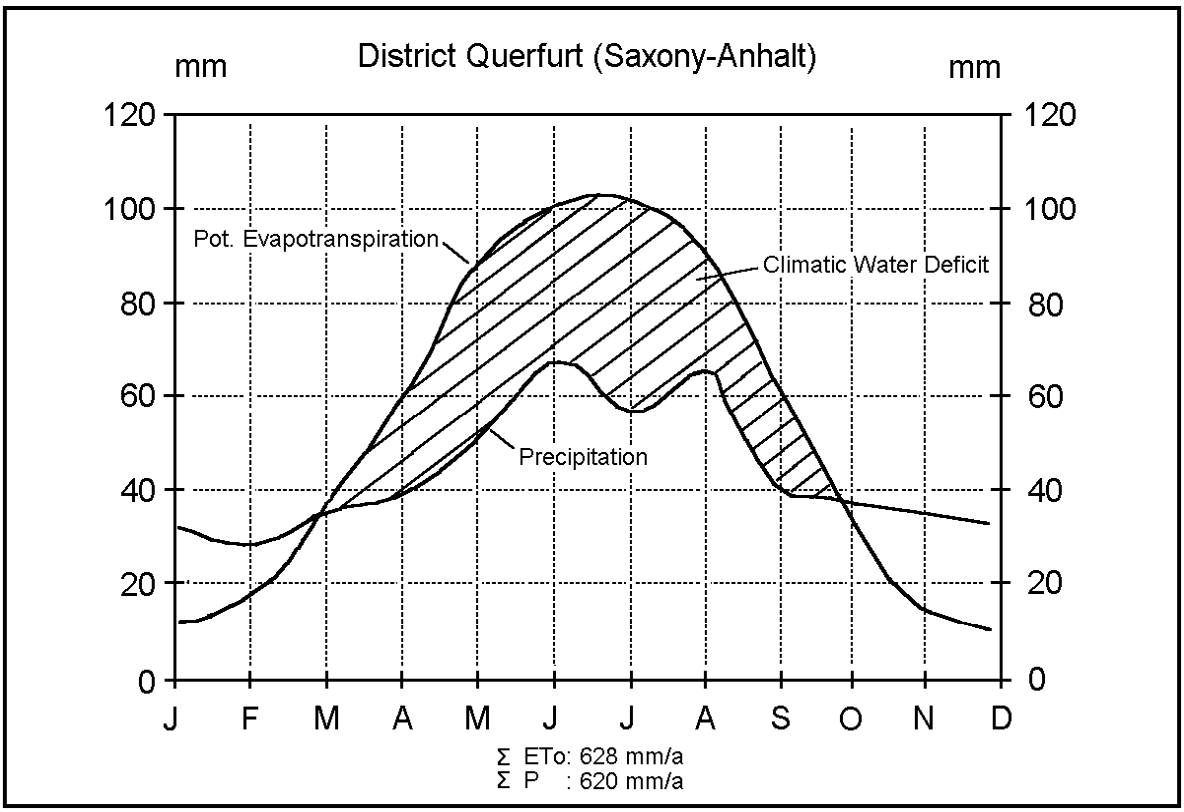
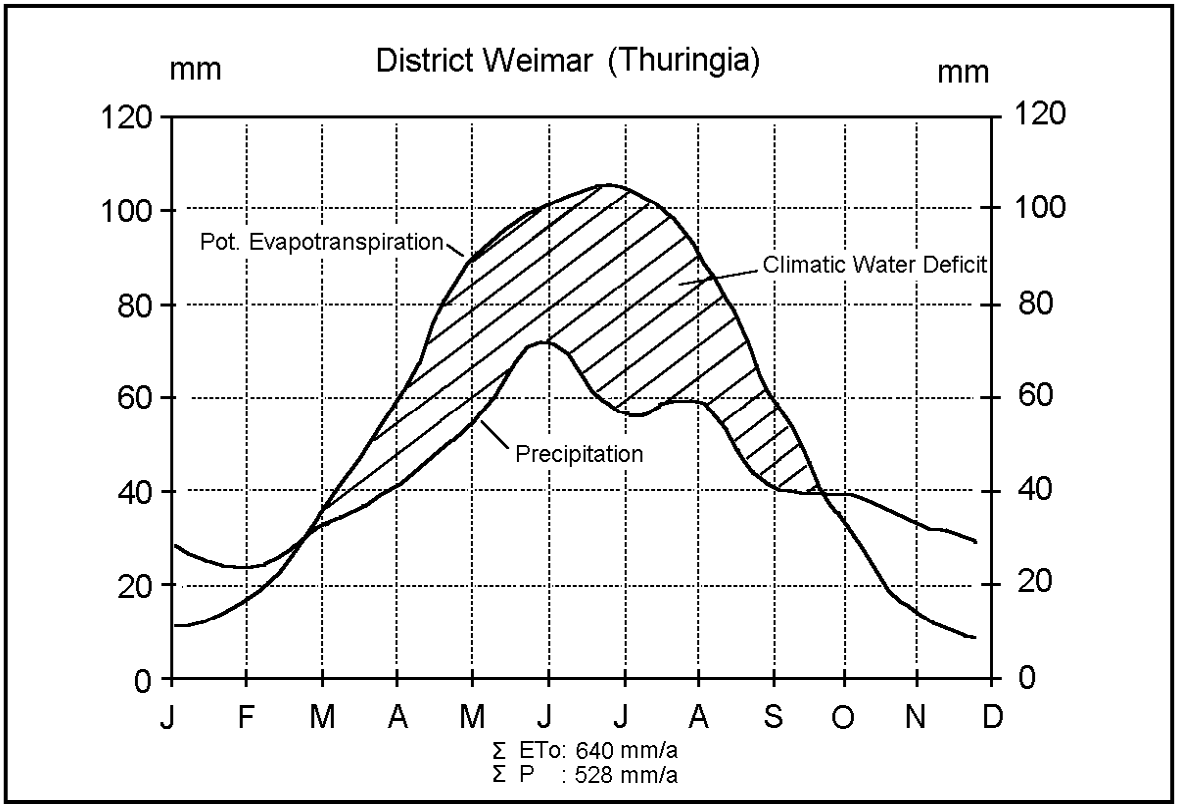
Annex



Distribution of precipitation in Germany
Source: Roth et al. 1993





Climatic water balance of two districts in East Germany
Source: Roth et al. 1993