AGRICULTURAL DRAINAGE publication series

Planning an Agricultural Subsurface Drainage System

by Jerry Wright and Gary Sands

*The **Agricultural Drainage** series covers such topics as basic concepts; planning and design; surface intakes; economics; environmental impacts; wetlands; and legal issues.*

GENERAL CONSIDERATIONS

Many soils in Minnesota and throughout the world would remain wet for several days after a rain without adequate drainage, preventing timely fieldwork, and causing stress on growing crops. Saturated soils do not provide sufficient aeration for crop root development, and can be an important source of plant stress. That's why artificial drainage of poorly draining soils has become integral to maintaining a profitable crop production system. Some of the world's most productive soils are drained, including 25 percent of the farmland in the United States and Canada.

Planning an effective drainage system takes time and requires consideration of a number of factors, including:

- Local, state, and federal regulations
- Soil information
- Wetland impact
- Adequacy of system outlet
- Field elevation, slope (grade), and topography assessment
- Economic feasibility
- Present and future cropping strategies
- Environmental impacts associated with drainage discharge
- Easements and right-of-ways
- Quality of the installation

The U.S. Department of Agriculture (USDA) Food Security Act and the farm bills of 1985, 1990, and 1996 created many special wetlands restrictions and mandates that all drainage projects, including upgrades, must follow. It's also very important that the landowner, system designer, and contractor understand other applicable federal laws, as well as the local watershed and state laws dealing with drainage. People considering installation of a drainage system should also know their rights and responsibilities concerning the removal of water from land and its transfer to other land. So the first steps of any installation project should always include visits to the offices of the Soil and Water Conservation District (SWCD), the Natural Resources Conservation Service (NRCS), and the local watershed administrative unit.

While developing a drainage plan and specifications, it's useful to consult a number of information sources. These include county soil and site topography surveys, the *Minnesota Drainage Guide*[1], local drainage experts, Farm Service Agency aerial photos, and ditch and downstream water management authorities. It's also a good idea to do some surface and subsurface evaluation of a field.

ECONOMICS

To decide whether a new drainage system (or improving an existing system) makes economic sense, it's necessary to determine or estimate the following: (1) what the crop response might be for the area to be drained, (2) the impact of a system on the timeliness and convenience of field operations, and (3) changes in inputs and other costs associated with a drainage system. Needless to say, it's not easy to estimate some of these factors. Data gathered from a combine yield monitor may offer good information on the yield range and variability of a field, as well as crop response to previous drainage activities. Crop response information from Iowa, Ohio, and Ontario specialists (see **Table 1**) could also be helpful.

Table 1. Crop yield response to subsurface drainage for various regions (bu/acre increase)

Crop	Iowa[2] 1984–1986	Ohio[3,4] 1962–1980	Ontario[5] 1979–1986
Corn	10 to 45	20 to 30	26
Soybeans	4 to 15	7 to 14	7
Spring Grain			22
Winter Wheat			17

Other potential sources for yield response information related to improved drainage include neighbors, county Extension educators, and the SWCD office. Many county soil surveys have also identified the potential yield for each soil type for common crops using sound management practices. A detailed financial analysis using the Ohio crop response information can be found in "Minnesota Farmland Drainage: Profitability and Concerns."[6] A simplified on-line profitability analysis, developed by the University of Minnesota Extension Service, can be performed at the following website: http://www.prinsco.com/farm.cfm. Advanced Drainage Systems (ADS) also offers a CD version of a simplified profitability analysis for drainage investments. Contact your local dealer for more information. These simplified analyses can give you a first guess at overall profitability, but lack the sophistication required to fine-tune investment decisions.

SYSTEM CAPACITY and DRAINAGE COEFFICIENT

To protect crops, a subsurface drainage system must be able to remove excess water from the upper portion of the active root zone 24 to 48 hours after a heavy rain. (See *Agricultural Drainage Publication Series: Soil Water Concepts*, BU-07644-S, for more information on excess, or drainable, soil water.) The drainage system capacity selected for most northern Midwest farmlands should provide the desired amount of water removal per day, commonly referred to as the "drainage coefficient." This figure is often between 3/8 and 1/2 inch of water removal per day. **Table 2** shows drainage coefficients guidelines for crop production for land that has adequate surface drainage. (The figures are from Chapter 14 of the *NRCS Engineering Field Handbook*).

Any refinement of these drainage coefficient guidelines should be done after consulting with drainage experts and local drainage contractors. NRCS literature suggests the drainage coefficient may need to be increased where one or more of these situations occur:

- The crop has high value (e.g., sugar beets or other vegetable/truck crops)
- Soils have a coarser texture
- Crops have a lower tolerance to wetness
- The topography is flat (implying poorer surface drainage)
- Large amounts of crop residue are left on a field
- There is little or poor surface drainage
- Crop evapotranspiration is low
- Frequent and low intensity rain is common
- Planting and harvest times are critical

Where it is necessary to convey surface water to the subsurface drainage system through surface inlets. NRCS literature suggests use of the drainage coefficients in the bottom half of Table 2, depending on inlet and soil type. The selected coefficient should be applied to the entire watershed contributing runoff to the surface inlet unless a portion of the runoff is drained by other means.

Table 2. General drainage coefficients (inches/24 hours).

Without surface inlets		
Soil Type	**Field Crops**	**Truck Crops**
Mineral	3/8 to 1/2	1/2 to 3/4
Organic	1/2 to 3/4	3/4 to 1 1/2

With surface inlets				
Soil Type	**Field Crops**		**Truck Crops**	
	Blind Inlets	*Open Inlets*	*Blind Inlets*	*Open Inlets*
Mineral	3/8 to 3/4	1/2 to 1	1/2 to 1	1 to 1 1/2
Organic	1/2 to 1	3/4 to 1 1/2	3/4 to 2	2 to 4

TOPOGRAPHY and SYSTEM LAYOUT

The goal of drainage system layout and design is to provide adequate and uniform drainage of a field or area. Field topography and outlet location/elevation are typically the major factors considered in planning drainage system layout, with topography greatly influencing what layout alternatives are possible. It's best to create a topography map of the field showing the elevations of the potential or existing outlet(s). A number of methods may be used to create the map, including standard topography surveys, a GPS or a laser system. The topography map helps the designer assess overall grade and identify the high or low spots in a field that might pose challenges.

The system outlet, whether an open channel or a closed pipe, must be large enough to carry the desired drainage discharge from a field quickly enough to prevent significant crop damage. Drainage outlets are typically located three to five feet below the soil surface. Sometimes pumping is required to create an adequate outlet. The bottom of an outlet pipe should be located above the normal water level in a receiving ditch or waterway. It is expected that floods or high water levels may submerge the outlet briefly. Drainage outlets must be kept clean of weeds, trash, and rodents. Outlets must also be protected from erosion, damage from machinery and cattle, and ice in flowing water.

Although there may be many possible layout alternatives for a given field (see **Figure 1**), specific drainage goals should be evaluated to find the best layout. These goals include removing water from an isolated problem area, improving drainage in an entire field, intercepting a hillside seep, and so on. Farmers and designers should approach system layout and drainage needs in a broad, comprehensive manner, anticipating future needs where possible. Even if a drainage system is installed on an incremental basis—some this year, more next year, and so on—system planning should not be piecemeal. Additions to a system will be much easier to make if the established mains are already large enough and located appropriately.

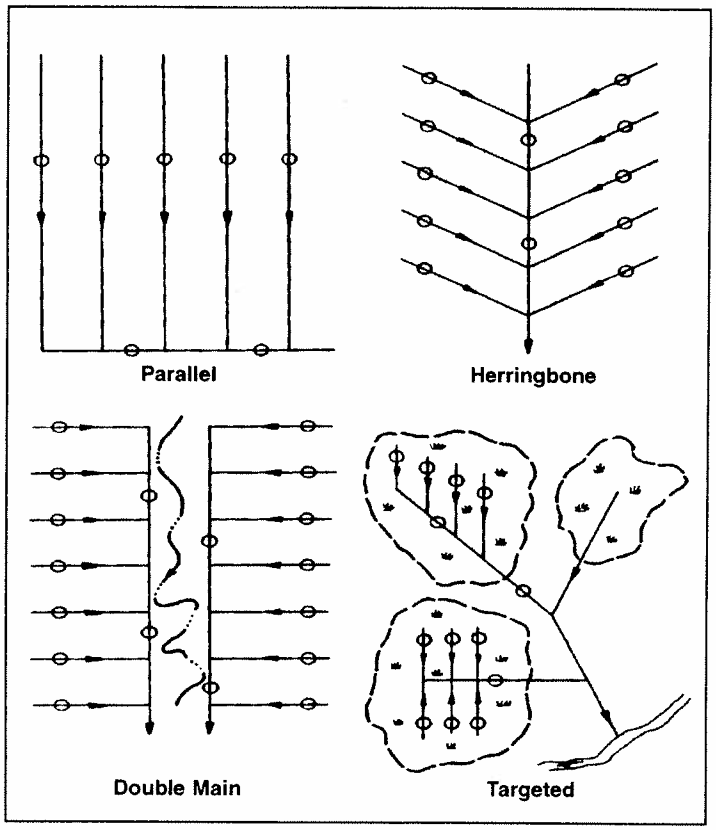

Fig. 1. Various drainage system layout alternatives.

When selecting a layout pattern for a particular field or topography, lateral drains, or field laterals, should be oriented with the field's contours as much as possible. This way, laterals can "intercept" water as it flows down-slope. Mains and submains (also called "collectors"), on the other hand, can be positioned on steeper grades, or in swales, to facilitate the placement of laterals (see **Figure 2**).

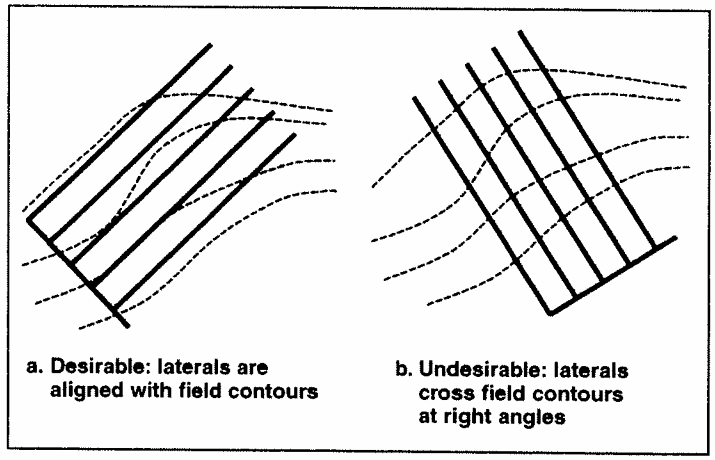

Fig. 2. Alignment of field laterals with contours.

DRAIN DEPTH and SPACING

A close relationship exists between soil permeability and the recommended spacing and depth of drains. When a system of parallel laterals is used, the drain spacing and depth should be considered simultaneously, based on soil type, soil permeability and stratification, the crops to be grown, the desired drainage coefficient, and the degree of surface drainage. If there is an abrupt transition from lighter to heavier soil, it's better to keep the drains above the heavy layer, when possible. Spacing drains closer together results in a higher drainage coefficient and faster drainage. The answer to the question "How close is close enough?" involves balancing costs and benefits. Simply stated, the increased cost associated with narrower drain spacings can only be justified to a point. After that, the only result is decreasing profits.

An ideal drainage system would have a uniform drain depth. In the real world, topography and system layout determine the actual depths of drains. A system layout that matches poorly with field topography will result in a wide variation of drainage depths and uneven field drainage. Avoid a system layout with many points of minimum cover (2–2½ ft) and excessively deep cuts.

Make decisions on drain spacing and depth after consulting NRCS literature and talking to people in the area with drainage experience. **Table 3** shows

SOIL NAME UNIT KIND MODIFIER	ID NO.	DRAIN DESIGN RECOMMENDATIONS COMMENTS	DSN GRP	DRAIN DEPTH In.	SPACINGS, Ft. DRAINAGE COEFF. In./24 Hrs. 1/4	3/8	1/2	3/4	HORIZ DEPTH In.	
BLUE EARTH SERIES	MN0064		1						0-10	PT
			5	36	95	74	62	49	0-10	OL,ML
			5	48	121	96	81	64	0-60	OL,ML
									60-70	CL,ML

Fig. 3. Minnesota Drainage Guide drainage spacing recommendations for a Blue Earth Series soil, for 36- and 48-inch depths and four drainage coefficients.

the most general spacing and depth options that might be considered during the early planning phase of a new or improved system. The *Minnesota Drainage Guide*[1] contains a table of drain spacing recommendations for many soils in Minnesota. **Figure 3** shows an example for a Blue Earth soil.

DRAIN SIZING

The maximum amount of water a drainage pipe can carry (its capacity) depends on the pipe's inside diameter, the grade or slope at which it's installed, and what the pipe is made of (e.g., smoother pipe has a greater flow capacity, all else being equal). Typically, full-flow pipe capacities for specific grades, pipe sizes, and pipe materials can be obtained from a number of sources:

Manufacturers' literature

- Nomographs (charts) in the *Minnesota Drainage Guide*[1]
- Pocket slide charts available from companies such as Prinsco, ADS, and Hancor
- On-line calculators (http://d-outlet.umn.edu or http://www.prinsco.com/farm.cfm)
- Local drainage contractors and engineers

Table 3. General parallel drain lateral spacing and depths for different soils.

Soil Type	Subsoil Permeability	Drain Spacing (ft) for: *Fair Drainage* $^1/_4$ *in*	*Good Drainage* $^3/_8$ *in*	*Excellent Drainage* $^1/_2$ *in*	Drain Depth (ft)
Clay loam	Very low	70	50	35	3.0–3.5
Silty clay loam	Low	95	65	45	3.3–3.8
Silt loam	Moderately low	130	90	60	3.5–4.0
Loam	Moderate	200	140	95	3.8–4.3
Sandy loam	Moderately high	300	210	150	4.0–4.5

To estimate the required flow capacity (Q) in cubic feet per second (cfs), multiply the area to be drained by the desired drainage coefficient (dc) and divide by the conversion factor (23.8).

$$Q(\text{cfs}) = \frac{\text{area (acres)} \times \text{dc (inches/day)}}{23.8}$$

(To use the equation in this form, area and dc must be in units of acres and inches/day, respectively.) Once Q is determined, pipe grade, material, and (ultimately) diameter can be selected to provide the required flow capacity. Topographical constraints typically determine pipe grade, so the pipe size is determined after the material is selected (e.g., corrugated polyethylene pipe, smooth interior pipe, etc.).

Besides flow capacity, drainage systems should also be designed to provide a certain minimum velocity of flow so that "self-cleaning" or "self-scouring" takes place. Where fine sands and silt are present, the minimum recommended velocity is 1.4 feet per second to keep sediments from accumulating in the system. Drainage systems in more stable soils can tolerate slower flow velocities, as low as 0.5 feet per second. **Table 4** shows the minimum grades recommended for various pipe sizes when using these flow velocities. These grades are supported by the American Society of Agricultural Engineers—ASAE EP260 standards. Flatter grades result in slower flow and run the risk of failure, and reverse grades, of course, must always be avoided.

Example: Find the flow capacity needed to drain 80 acres with a ½ inch/day drainage coefficient:

Q(cfs) = 80 ac x 0.5 in/day ÷ 23.8 = 1.7 cfs

Table 4. Minimum recommended grades (percent) for drainage pipes.

Drain Inside Diameter *(inches)*	**Drains not subjected to fine sand or silt** *(min velocity 0.5 ft/s)*		**Drains where fine sand or silt may enter** *(min velocity 1.4 ft/s)*	
	Tile	***Tubing***	***Tile***	***Tubing***
3	0.08	0.10	0.60	0.81
4	0.05	0.07	0.41	0.55
5	0.04	0.05	0.30	0.41
6	0.03	0.04	0.24	0.32
8–12*		0.07		
12 and larger*		0.05		

* recommendation for drain sizes is from NRCS—Minnesota Drainage Guide. For smooth interior CPT, use the "Tile" column.

Because excess water velocities could cause some pressure problems at drain joints or tube openings that might result in unwanted erosion of the soil around the drain, there are also suggested maximum grades for drain sizes and soil types. These suggestions are outlined in Chapter 4 of the *Minnesota Drainage Guide*[1].

Tables 5–7 show the potential land area that can be drained with various grades, drain sizes, and pipe materials using 1/4-, 3/8-, and 1/2-inch drainage coefficients. For other grades, sizes, materials, and drainage coefficients, consult one of the sources mentioned above. When computing drain size with any tool or chart, always round an intermediate size to the nearest larger commercially available size. For example, if a calculation calls for a 6.8-inch diameter pipe, select an 8-inch pipe, assuming a 7-inch pipe is not available.

USE OF DRAIN ENVELOPES (SOCKS)

A drain envelope, or "sock," is a material placed around a drain pipe to provide either *hydraulic function*, which facilitates flow into the drain, or *barrier function*, which prevents certain sized soil particles from entering the drain. Drain envelopes are not *filters*. Filters become clogged over time; drain envelopes do not. Many types of envelope material exist, from thick gravel and organic fiber to thin geotextiles. The useful life of a synthetic drain envelope is quite long, provided it is not left in the sun for a long time and exposed to too much ultraviolet radiation.

Fine-textured soils with a clay content of 25 to 30 percent are generally considered stable, so they don't need drain envelopes. A geotextile sock is recommended for coarse-textured soils free of silt and clay. These soils are considered unstable even if undisturbed, so that particles may wash into pipes.

The need for an envelope in intermediate soils (clay contents less than 25 to 30 percent) is best left to a professional contractor or soil and water engineer because soil movement is more difficult to predict.

ENVIRONMENTAL IMPACTS

Subsurface tile drainage systems can convey soluble nitrate-nitrogen (N) from the crop root zone. Implementation of nitrogen fertilizer Best Management Practices (BMPs) can reduce the potential loss of nitrate-N. Adding perennial crops to the rotation may also reduce N losses to surface waters in addition to decreasing water drainage. Farmers installing new or improved field drainage systems should consider using crop management practices and landscape structures that reduce nitrogen, sedimentation, and water discharge rates.

Table 5. Potential acres drained by drain size, type, and grade for a drainage coefficient of 1/4-inch per day.

% Grade ft/100-ft	**Drain Type**	**Drain Size** (inches)							
		4	**5**	**6**	**8**	**10**	**12**	**15**	**18**
0.1	CPE	5.0	9.0	14.6	32	50	82	126	206
	Smooth	7.5	13.5	22	47	86	140	253	411
0.2	CPE	7.0	12.7	21	45	71	116	179	291
	Smooth	10.5	19.1	31	67	121	197	358	582
0.3	CPE	8.6	16	25	55	87	142	219	356
	Smooth	12.9	23	38	82	149	242	438	712
0.4	CPE	10	18	29	63	101	164	253	411
	Smooth	14.9	27	44	95	172	279	506	823
0.6	CPE	12	22	36	77	124	201	310	504
	Smooth	18	33	54	116	210	342	620	1008
0.8	CPE	14	25	41	89	143	232	358	582
	Smooth	21	38	62	134	243	395	715	1163
1	CPE	16	28	46	100	160	260	400	650
	Smooth	24	43	69	150	271	441	800	1301
1.5	CPE	19	35	57	122	195	318	490	797
	Smooth	29	52	85	183	332	540	980	1593
2	CPE	22	40	66	141	226	367	566	920
	Smooth	33	60	98	212	384	624	1131	1840

CPE denotes corrugated polyethylene pipe (3"–8", n=0.015; 10"–12", n=0.017; >12", n=0.02) smooth denotes smooth-wall CPE, concrete or clay tile (n=0.01).

Table 6. Potential acres drained by drain size, type, and grade for a drainage coefficient of 3/8-inch per day.

% Grade ft/100-ft	Drain Type	Drain Size (inches)							
		4	5	6	8	10	12	15	18
0.1	CPE	3.3	6.0	9.8	21	34	55	84	137
	Smooth	5.0	9.0	15	32	57	93	169	274
0.2	CPE	4.7	8.5	14	30	48	77	119	194
	Smooth	7.0	12.7	21	45	81	132	238	388
0.3	CPE	5.7	10	17	36	58	95	146	237
	Smooth	8.6	16	25	55	99	161	292	475
0.4	CPE	7	12	20	42	67	109	169	274
	Smooth	9.9	18	29	63	114	186	337	548
0.6	CPE	8	15	24	52	82	134	207	336
	Smooth	12	22	36	77	140	228	413	672
0.8	CPE	9	17	28	59	95	155	238	388
	Smooth	14	25	41	89	162	263	477	776
1	CPE	10	19	31	67	106	173	267	434
	Smooth	16	28	46	100	181	294	533	867
1.5	CPE	13	23	38	81	130	212	327	531
	Smooth	19	35	57	122	222	360	653	1062
2	CPE	15	27	44	94	150	245	377	613
	Smooth	22	40	66	141	256	416	754	1226

CPE denotes corrugated polyethylene pipe (3"–8", n=0.015; 10"–12", n=0.017; >12", n=0.02) smooth denotes smooth-wall CPE, concrete or clay tile (n=0.01).

Table 7. Potential acres drained by drain size, type, and grade for a drainage coefficient of 1/2-inch per day.

% Grade ft/100-ft	Drain Type	Drain Size (inches)							
		4	5	6	8	10	12	15	18
0.1	CPE	2.5	4.5	7.3	16	25	41	63	103
	Smooth	3.7	6.8	11	24	43	70	126	206
0.2	CPE	3.5	6.4	10	22	36	58	89	145
	Smooth	5.3	9.6	16	33	61	99	179	291
0.3	CPE	4.3	8	13	27	44	71	110	178
	Smooth	6.5	12	19	41	74	121	219	356
0.4	CPE	5	9	15	32	50	82	126	206
	Smooth	7.5	14	22	47	86	140	253	411
0.6	CPE	6	11	18	39	62	101	155	252
	Smooth	9	17	27	58	105	171	310	504
0.8	CPE	7	13	21	45	71	116	179	291
	Smooth	11	19	31	67	121	197	358	582
1	CPE	8	14	23	50	80	130	200	325
	Smooth	12	21	35	75	136	221	400	650
1.5	CPE	10	17	28	61	98	159	245	398
	Smooth	14	26	43	92	166	270	490	797
2	CPE	11	20	33	71	113	184	283	460
	Smooth	17	30	49	106	192	312	566	920

CPE denotes corrugated polyethylene pipe (3"–8", n=0.015: 10"–12", n=0.017; >12", n=0.02) smooth denotes smooth-wall CPE, concrete or clay tile (n=0.01).

SURFACE INLETS (INTAKES)

Surface inlets remove ponded water that forms in closed basins or potholes in a field. These inlets, however, can provide a direct pathway for surface waters that may carry sediment and other pollutants to drainage ditches and other downstream surface water. The general public, resource managers, and others are concerned about the potential impacts of surface inlets to both the quality and quantity of downstream waters.

From a water quality perspective, almost any inlet configuration is preferable to using an open pipe that's flush with the ground surface. Of the traditional intakes available, the slotted or perforated riser is a good option because it promotes some settling of sediments in the basin during flow events.

Farmers in some areas have begun replacing traditional inlets with "blind" or "rock" inlets. These have the advantage of being farmable, and anecdotal evidence suggests they can remove water effectively. There are still questions, however, about the effective life of rock inlets. University of Minnesota researchers are currently investigating the performance characteristics of these and other alternative surface inlet designs. This work will ultimately lead to a better understanding of their effectiveness and longevity.

INSTALLATION QUALITY

A great deal of careful consideration goes into installing a drainage system. Drain depth, grade, pipe size, and field layout are all extremely important design factors that will determine how well a system performs. But the installation method is also key to a successful system. It's why special care should be taken to ensure that every installation is on grade and of high quality.

Because quality installation is important, an experienced installer is usually an asset. It's also important to know the limitations of equipment. Although pull-type and tractor-mounted drainage plows or trenchers can often perform adequately, they face limitations in the field that, when improperly accounted for, can result in installation and performance problems. Field irregularities such as dead furrows, fence lines, ridges, swales and rocks can pose installation problems for these machines. In addition, operators have found it difficult to make cuts deeper than five feet.

SUMMARY

Improved surface and subsurface drainage is necessary for some Minnesota soils to optimize the crop environment and reduce production risks. To assure an effective and profitable system, it's important to couple a good design process with the thorough evaluation of such on-site factors as soil type, topography, outlet placement and existing wetlands. This, and a quality installation will ensure a drainage system that will perform effectively for many years to come.

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OTHER RESOURCES

Agricultural Drainage Publication Series: Soil Water Concepts, 2001,Pub # 07644. University of Minnesota Extension Service, St. Paul. To order call 800-876-8636

Many of these publications and other related resources can be found in the Education and Information Section at **http://d-outlet.coafes.umn.edu/**

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The Extent of Farm Underdrainage in England and Wales, prior to 1939

By M ROBINSON

FIELD drainage in Britain probably dates from Roman times, but it is only in the last 200 years that significant amounts have been carried out. Enclosure of the common lands beginning in the seventeenth century was a necessary precursor to agricultural improvement and from about 1750 there was an increase in the amount of drainage carried out. The drains at this time were mainly made of stones or brush wood, and it was only from the beginning of the nineteenth century with the invention of clay drainage pipes that drainage became more widespread. After 1826 drainage tiles were exempted from tax, and in 1845 Thomas Scragg invented a machine for extruding drainage tiles, which brought their price down by about 70 per cent. This began a period of intensive drainage which continued for about half a century, helped by loans from government and private sources. However in the period of agricultural depression which began about 1890 and continued until the 1930s very little drainage was carried out.[1] In more recent years with grant-aid and advice available from the Ministry of Agriculture, Fisheries and Food (MAFF), and with high food prices, there has been considerable renewed interest in farm drainage.[2] Whilst records are available of grant-aided drainage for the period after 1939, and these are thought by the MAFF to represent almost all the recent drainage that has taken place, there is in contrast, little information on the amount of drainage in the nineteenth century. And what historical records do exist, are conflicting and inconclusive.

I

The most frequently quoted source of information is the evidence that Bailey Denton submitted to the Agricultural Commission in 1880.[3] He estimated that one million acres (approx 4,000 km^2) in England and Wales had been drained with government loans, and that in addition perhaps double that amount had been drained with private finance. Only seven years earlier he had also estimated the total area drained as 3 million acres (12,000 km^2) but based it on equal amounts of privately and publicly funded drainage.[4] The area drained by government loans can be approximated from records of the sums loaned, but estimates of the amount of privately funded drainage are very uncertain and have often been assumed to be a given multiple of the government drainage. Denton changed his estimate of the ratio of public to private finance from 1:1 to 1:2, whilst his contemporary Caird[5] used the ratio of 1:3. Thus with only minor changes in the numbers used, the estimates of the total area drained could vary between 2 and 4.5 million acres. In a review of the historical sources of evidence, Phillips[6] stated that 'It is unwise to put any confidence in estimates which are so variable and unreliable,' and concluded 'The

[1] H H Nicholson, 'Modern Field Drainage', *Journal of the Royal Agricultural Society of England*, 104 (1943), pp 118–35; B D Trafford, 'Field Drainage', *JRAS*, 131 (1970), pp 129–52.

[2] A C Armstrong, 'A digest of drainage statistics', Field Drainage Experimental Unit (1978), MAFF, 68 pp.

[3] J Bailey Denton, 'Submission to the Royal Commission on the Depressed Condition of the Agricultural Interests 1880–2', *British Parliamentary Papers*, XV (1881).

[4] J Bailey Denton, 'Submission to the Select Committee of the House of Lords on the Improvement of Land', *BPP*, XVI (1873).

[5] J Caird, 'Submission to the Select Committee of the House of Lords on the Improvement of Land', *BPP*, XVI (1873).

[6] A D M Phillips, 'Underdraining and the English Claylands, 1850–80: a Review', *Ag Hist Rev*, 17 (1969), pp 44–55.

acreage drained during the period 1850–80 is unknown.' More precise evidence is available for individual local areas from the records of estates.[7] However it would be dangerous to extrapolate their drainage figures to larger areas since the estates often had the money and labour available to carry out this work, and so were not necessarily typical of countryside as a whole.

Trafford[8] examined Denton's records and considered that a more reliable calculation of the area underdrained in the nineteenth century could be obtained from estimates of the number of clay pipes manufactured each year. Assuming an average of 1250 pipes needed to drain each acre and after an allowance for sales outside England and Wales, he concluded that probably about 12 million acres (about 50,000 km^2) were underdrained. This is considerably higher than the earlier estimates of Caird and Denton. In support of this figure Trafford quoted the frequent occurrence of old clay pipes when a field is drained[9] and the findings of a survey of drainage need carried out by the MAFF.[10] The MAFF selected a random sample of 5 per cent of England and Wales and asked the local field drainage advisers for their 'opinions' of the percentage of land which fell into the following categories: (i) drained since 1939, (ii) naturally freely draining (eg chalk soils), (iii) adequate drainage by old (pre-1939) drains, (iv) in need of drainage (either undrained or where existing drainage was inadequate or had failed), (v) uneconomic to drain. This indicated that about 5.3 million acres (21,000 km^2) relied on old drains, and since there was so little drainage in the early part of this century, Trafford argued these might reasonably represent the remnant of up to 12 million acres drained in the nineteenth century. Thus, far from identifying which nineteenth-century estimate was the more accurate, modern agriculturists have cast doubt on all the estimates by computing an area which is greater by a factor of 3 to 6. It is to provide an independent estimate from a new source of evidence that this paper is directed.

II

Clearly, a definitive assessment could be provided by a field to field survey looking for the occurrence of old drains feeding into watercourses. This would be prohibitively expensive and time-consuming, but Green[11] showed that very similar information, however, can be obtained from records that have been routinely collected by the MAFF since 1971. Up to the early 1980s all applications by farmers for government grant-aid for drainage required a visit to the site by a MAFF drainage adviser. The drainage officer advised on the layout of the new drainage scheme and noted a number of features of the site, including the existence of pre-1939 drains. This information was based on site inspection and discussion with the farmer. Since grant-aid for drainage became available in 1939 few farmers have carried out the work privately, and the MAFF statistics provide a very complete record of drainage.[12] Over the decade 1971–80 there were nearly 125,000 grant applications, requiring visits to about 8500 km^2 of farmland, with an average area inspected of under 7 hectares (17 acres). This provides a great deal of information on the extent of old drains, both the total area of land drained, and its regional distribution. These and other statistics were collated by the MAFF for each parish for the period 1971–80, and the data have been made available to the author.

The area with old underdrainage in a parish may be estimated from these data if it

[7] A D M Phillips, 'The development of underdraining on a Yorkshire estate during the nineteenth century', *Yorkshire Archaeological Journal*, 44 (1972), pp 195–206.

[8] Trafford, *op cit*.

[9] H H Nicholson, *The Principles of Field Drainage*, Cambridge, 1953.

[10] E T Belding, 'Drainage Survey in England and Wales', *Agriculture*, 78 (1971), pp 250–4.

[11] F H W Green, 'Field underdrainage before and after 1940', *Ag Hist Rev*, 28 (1980), pp 120–3.

[12] Trafford, *op cit*.

is assumed that the land inspected was a random sample, typical of that parish. Then the percentage of the land found to have old drains would be representative of the parish as a whole. This assumption is not unreasonable for parishes that are homogeneous in soils and topography, but will result in inaccuracies for those in which only a part of the land was suitable for drainage. For example where significant areas had adequate natural drainage, then the area in the parish with old drains would be overestimated. On the other hand, underestimates would result for parishes in which many old drainage systems still function satisfactorily, since those fields would not be inspected, and so would not be included in the data collection. These and other sources of potential uncertainties in the data used in this paper are summarized in Table 1. As with the other estimates of nineteenth century drainage described earlier it is difficult or impossible to quantify the likely magnitude of the inaccuracies, but some qualitative guidance can be given. The possibility that the inspected areas in a parish were an unrepresentative sample is probably the most important source of error. However, it should be noted that the heterogeneity of a parish would be limited by its small size (average area under 10 km²), and that any error could be positive or negative. Similarly, whilst the drainage adviser's report does not identify cases where only a part of the land contained old drains, there would undoubtedly have been many instances in which old drainage systems were not detected. Some short-lived twentieth-century drainage schemes might have been counted in error, but this is unlikely to have been a serious source of error. Grant aid was only available to replace drains installed before 1939; any later schemes would have been noted in the MAFF's records and not been eligible. Nineteenth-century drainage pipes are very different in appearance to modern pipes, being of different sizes and shapes, often poorly extruded, and many stamped 'DRAIN' to be exempted from tax. The significance (or otherwise) of these sources of error, and the extent to which they cancel out, cannot be determined. What is, however, beyond dispute is that the figures are based on site visits to a much larger sample than is ever likely to be studied again. These visits were discontinued by the MAFF in 1981 due to the enormous amount of work involved. The nineteenth-century estimates have been shown to be unreliable and conflicting,[13] and the present method provides an entirely independent approach to the problem.

TABLE I

Potential Sources of Uncertainties in Estimating Nineteenth-Century Drainage from the Parish Data

Overestimates

1 Unrepresentative sample of land inspected within parish — other areas might have fewer or no old drains.

2 Only a small part of the site inspected might contain old drains.

3 Short-lived schemes installed earlier in this century might be included in error.

Underestimates

1 Unrepresentative sample — other areas might have adequately functioning old drains.

2 Old drains at a site might be unknown to the farmer, and not found when the site was inspected.

Summing the values for all the parishes produces a figure of 57,000 km² (14 million acres) with old drains, which represents 52 per cent of the agricultural land in England and Wales. Given the uncertainties and assumptions of the two approaches this is remarkably similar to the estimate of 50,000 km² (12 million acres) obtained by Trafford[14] from figures for clay pipe production. These two independent estimates, taken with the Belding[15] figure of over 5 million acres having nineteenth-

[13] Phillips, *Ag Hist Rev*, 17 (1969).
[14] Trafford, *op cit*.
[15] Belding, *op cit*.

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century drains still functioning, indicate that the extent of underdrainage in the mid- to late-nineteenth-century period of 'High Farming' was very much greater than contemporaries such as Denton and Caird realized. Even if the lower figure of 50,000 km^2 is assumed, due to the sources of overestimation outlined above and on the basis of the regional analysis described in the next section, this represents an enormous achievement by the agricultural community and one which must have been largely financed by private loans or from farmers' own resources (and so largely unrecorded in historical sources). The extent of this effort may be judged by comparison with the amount of drainage in the present century. In the period 1940–81, just under 20,000 km^2 were drained with government assistance. Although many of these schemes would be expected to be of a much higher standard than those of the nineteenth century they amount to under one half of the land area improved then. Figures for drainage pipe production confirm the difference between the two centuries.[16] Annual production in the mid-nineteenth century was about four times that at present (partly due to closer spacing in old schemes).

Additional, although indirect, evidence of the large extent of drainage in the last century comes from the concern that was expressed about the effect this work was having on the flows in rivers. As early as 1861 a special meeting was convened in London by the Institution of Civil Engineers to discuss whether drainage increased the discharge of water from farmland into the rivers in storm periods, and so resulted in an increase in the incidence of flooding of areas downstream.[17] No conclusions could be reached, however, due to the lack of measurements of river discharges.

III

The parish drainage data described above can also be used to study the regional variations in drainage activity in England and Wales, although it must be recognized that the figures will be less reliable as smaller areas are considered. Grid references of all the parishes were obtained from the Ordnance Survey. To produce an intelligible map based on nearly 12,000 (parish) data points, it was necessary to contour the data, and for convenience and consistency a computer plotting package was adopted.[18] This provides a range of options to control the contouring and the degree of smoothing needed, depending on the amount of variation in the data. A number of trial maps were produced until one was selected as representing the best balance between spatial detail and clarity. This map has been redrawn with shading as Figure 1.

The pattern of drainage shows a good overall agreement with the spatial pattern of soils based on their hydrological properties.[19] Areas of low drainage activity can be readily identified with areas of permeable soils having good natural drainage (eg the Downs, Cotswolds and Chilterns in southern England and the Yorkshire Wolds in northern England). Higher rates of drainage occur in areas with more impermeable soils such as the clay soils of Essex, Suffolk and Lincolnshire, and the Weald in Surrey and Sussex. The highest rates lie in the north and west; these are high rainfall areas associated with low permeability peaty or heavy clay soils. The high frequency of occurrence of old drains in soils with poor natural drainage confirms the observation that 'In those parts of England and Wales where artificial drainage is necessary it is rare to find a field which has not been drained at some time or another; and much of the work

[16] Trafford, *op cit*.

[17] J Bailey Denton, 'On the discharge from underdrainage and its effects on the arterial channels and outfalls of the country', *Proceedings of the Institution of Civil Engineers*, 21 (1862), pp 48–130.

[18] R J Sampson, *SURFACE II Graphics System*, Kansas Geological Survey, 1978.

[19] F A K Farquharson, D Mackney, M D Newson, and A J Thomasson, 'Estimation of runoff potential of river catchments from soils surveys', *Special Survey No 11*, Soil Survey of England and Wales, Harpenden, 1978.

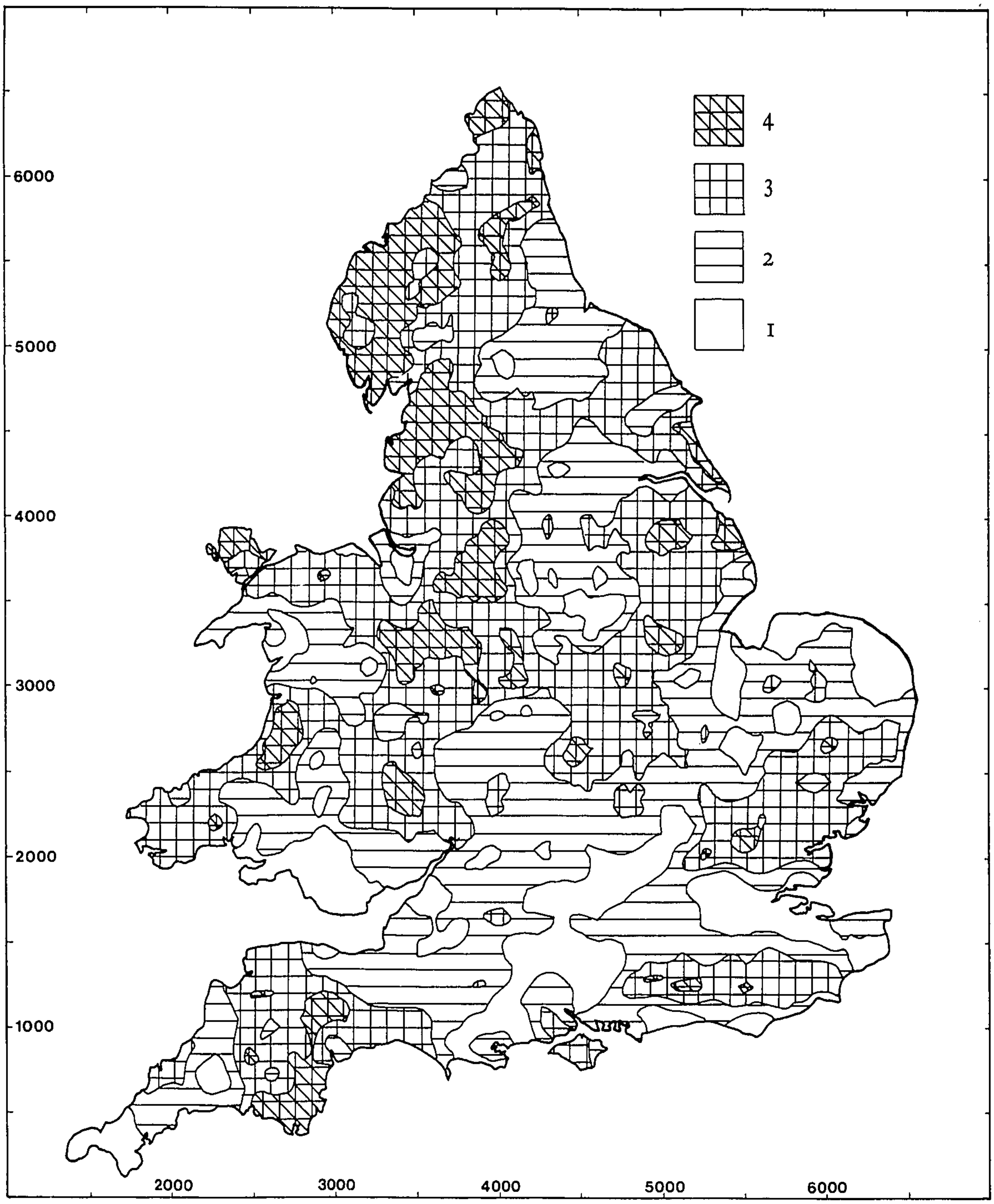

FIGURE I

Percentage of agricultural land found to contain field drains that had been installed prior to 1939.
(1 = under 25 per cent, 2 = 25 to 50 per cent, 3 = 50 to 75 per cent and 4 = over 75 per cent)

being carried out today consists of reconditioning or replacing old system.'[20] However, whilst the overall pattern appears reasonable it is questionable that such high percentages were drained in upland areas such as Cumbria and northern Lancashire where the economic return on drainage would be poor. Further investigation indicates that in such areas underdrainage was likely to be concentrated on the enclosed 'in-bye' fields in the valleys with the intervening hill land remaining undrained (both now and in the nineteenth century). The percentage of the land in a parish found to have old drains would thus be biased towards these more fertile valley bottom lands. It is difficult to determine the magnitude of the resulting overestimation but the survey of Belding[21] described earlier and based on a random sample of land provides *minimum* estimates of the area with old drains, since the schemes that had failed would be on land included in other categories. Summing the land in all drainage categories except that with naturally freely draining soil provides a rough estimate of the potential *maximum* area with old drains. These minimum and maximum values yield ranges of about 35–80 per cent of the land in northern England compared with only about 10–40 per cent in southern England and Wales. This confirms that higher rates of drainage occurred in the north and west, but suggests, as indicated above, that the parish data result in a systematic overestimation for hill areas. Taking these figures into consideration it seems reasonable to revise the national estimate of 57,000 km^2 underdrained in the nineteenth century to a lower figure of about 50,000 km^2.

The conclusion that drainage rates were higher in the north and west than in the rest of the country has also been made by some agricultural historians, and the role of large estates has been cited. Sturgess[22] argued that nineteenth-century drainage was concentrated on the clay soils of the north and west of the country since only with drainage to prevent waterlogging of crops in winter could agricultural production in those regions be increased. This change took place at a time of depressed corn prices (the traditional clayland crop) and was often associated with a change to grass, mostly for cattle production. On the lighter soils, increased production was achieved by the introduction of turnip husbandry. On the lowland clays in eastern England, the smaller rainfall limited the growth of grass in summer and made the investment of drainage a less economic prospect than in the wetter and more productive grass growing areas of the west and north. It is interesting to contrast this pattern with drainage in the present century which is concentrated on the arable land in eastern England.[23] This is a reflection of economic factors since this land is used to grow cash crops such as corn, sugar beet and potatoes. There is a high investment in equipment, and the need to maximize economic returns. Artificial drainage both improves crop yields and increases the time during the year that heavy machinery can be used on the land.

IV

The site visit records completed by MAFF drainage officers provide a unique source of information from which to estimate the proportion of land with old drains. Due to the agricultural depression in the early part of this century, these will be mostly nineteenth-century drains. This gives an estimate that about 50,000 km^2 of farmland was drained, and is consistent with an

[20] MAFF, 'Land Drainage in England and Wales', Report of the Land Drainage Legislation Sub-Committee of the Central Advisory Water Committee, 1951.

[21] Belding, *op cit*.

[22] R W Sturgess, 'The Agricultural Revolution on the English Clays', *Ag Hist Rev*, 14 (1966), pp 104–21; *idem*, 'The Agricultural Revolution on the English Clays: a Rejoinder', *Ag Hist Rev*, 15 (1967).

[23] F H W Green, 'Recent changes in land use and treatment', *Geographical Journal*, 142 (1976), pp 12–26.

independent estimate based on drainage pipe production. This suggests that contemporaries greatly underestimated the amount of draining taking place in the last century, although as early as the 1860s fears were voiced of the effects farm drainage might be having on river flows. The area of land drained was considerably in excess of that drained in the present century, much of which is replacing old drains that have reached the end of their useful life. Drainage in the nineteenth century extended to most parts of the country, but was greatest in the north and west. These are areas with high rainfall and soils having poor natural drainage.

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Supplement to the Bibliography of Theses on British Agrarian History: Omissions and Additions 1981–83*

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