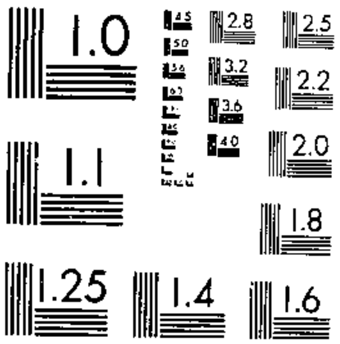
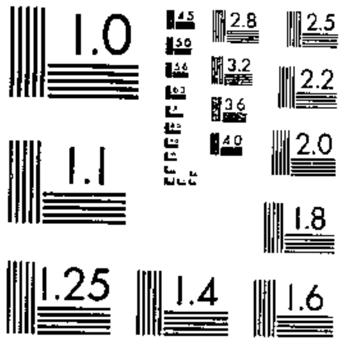
TB 269 (1931)   USDA TECHNICAL BULLETINS   UPDATA
ECONOMICAL USE OF LARGE TILE FOR LAND DRAINAGE
MARSDEN, R D   1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL BULLETIN No. 269 NOVEMBER, 1931

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

ECONOMICAL USE OF LARGE TILE FOR LAND DRAINAGE

By ROGER D. MARSDEN
Senior Drainage Engineer, Bureau of Agricultural Engineering

CONTENTS

PURPOSE AND SCOPE OF THE INVESTIGATION

There are probably 18,000,000 acres in the United States embraced in drainage districts using tile wholly or in part. These public tile drains have an estimated length of about 50,000 miles and cost perhaps more than $100,000,000. The census of 1920 showed 177 counties in seven North Central States to have drains of 30-inch and larger tile.

The use of large tile for land drainage increased greatly from 1910 to 1920, especially in Iowa and Minnesota where land values increased most rapidly. Tile drains have some evident advantages, but in large sizes cost very much more to construct than open ditches of equal capacity. The economy of using them has been questionable in many instances.

To study the economy of using large draintile, drainage records were examined in 31 counties in Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan, and Ohio, and county and drainage district officials, landowners, and drainage engineers were interviewed in these and other counties. In the four States first named, figures were obtained useful in comparing the entire cost—installation and maintenance—for tile drains and open ditches. The greater portion of the data presented herein were obtained in Iowa.

67751—31——1

REASONS FOR USING LARGE TILE

Landowners have assumed the burden of the extra cost of using tile in order to avoid having unsightly ditches and waste banks across their farms, to prevent division of their fields and interference with farming operations, and to be free of periodical expense for cleaning or redigging the drains. Doubtless in many cases landowners have been influenced to assume this burden by the belief that the damages they would receive from the district for the construction of an open ditch across their lands would be less than the actual loss resulting to them from such construction.

COSTS OF INSTALLATION AND MAINTENANCE

The total cost of drainage for a district comprises (1) the installation cost, including organization and administration as well as materials and labor; and (2) the maintenance cost, including expenses for administration as well as those for actual repair of the drains. Interest on bonds or other indebtedness is not part of the cost of drainage. The installation cost is a capital investment; the maintenance cost is an annual charge. The equivalent investment for the maintenance cost has been computed for combining with the installation cost, though reduction of the installation cost to a perpetual annual charge would give the same results in comparing the two kinds of drains. The interest rate used in the computations herein is 6¾ per cent per year.

DRAINAGE WITH TILE

For 106 drainage districts comprising 87 in Iowa, 13 in Minnesota, and 6 in Wisconsin and Illinois, data as to period of construction, length and sizes of tile drains, installation cost, and maintenance expenditures were obtained as shown in Table 1. The districts have constructed about 570 miles of tile drains 5 to 40 inches in diameter at a total installation cost of about $1,863,000. The average costs of these districts have ranged from $1,066 to $10,813 per mile of drain. During periods of 3 to 15 years, averaging 7 years, the districts have expended some $60,000 for maintenance, the average annual expenses ranging from nothing to $193 per mile, and from 0 to 6.3 per cent of the installation costs.

For all these districts, the average annual expenditure (not including interest on indebtedness) has been about 0.67 per cent of the installation cost. This is about equivalent to an increase of 10 per cent in the installation cost if the interest rate on loans is 6¾ per cent.

DRAINAGE WITH OPEN DITCHES

For 18 drainage districts in the four States previously named, similar data were obtained concerning installation costs and maintenance expenditures for open ditches as shown in Table 2. These districts have constructed about 190 miles of ditches ranging from 3 to 26 feet in bottom width at a total installation cost of $409,000. The average costs of the districts have ranged from $549 to $4,784 per mile of ditch. The average annual maintenance expenses, for periods of 5 to 35 years, ranged from $2 to $508 per mile, and from 0.16 per cent to 13.10 per cent of the installation cost.

TABLE 1.—*Expenditures for maintenance and repair of tile drains in 106 drainage districts in Iowa, Minnesota, Wisconsin, and Illinois*

State and county	Drainage district No.	Construction period	Drains installed: Length	Drains installed: Sizes	Drains installed: Depth	Cost of district[1]: Total	Cost of district[1]: Per mile	Maintenance and repairs[2]: Period: Dates	Period: Length	Expenditures[2]: Total	Expenditures: Per year: Per mile	Expenditures: Per year: Per cent of cost
Iowa:			*Miles*	*Inches*	*Feet*	*Dollars*	*Dollars*		*Years*	*Dollars*		
Boone	1	1907–1909	2.4	14–18		13,369	5,570	1910–1919	10	399	$16.62	0.30
	104	1913	3.41	6–28	4.3–6.2	9,899	2,903	1915–1925	11	112	2.[illegible]	.10
	106	1914–1916	6.92	6–32	4.2–7.2	27,935	4,037	1917–1925	9	397	6.[illegible]7	.16
	107	1914–1915	6.18	6–36	4.2–8.5	19,647	3,179	1915–1924	10	269	[illegible].35	.14
	110	1914–1916	6.27	6–26	4.1–7.6	14,722	2,348	1917–1924	8	355	7.08	.30
Boone and Webster	Joint 1	1915–1917	8.99	6–40	4.6–11.4	58,710	6,531	1918–1923	6	230	4.43	.07
Total or average			34.17			144,282	[3] 4,095			1,771	[3] 6.97	[3] .18
Cerro Gordo	17	1913–1914	6.69	5–20	3.5–5.7	9,961	1,489	1915–1924	10	1,513	22.62	1.52
	18	1913	2.59	7–22	3.5–6.9	6,600	2,548	1914–1924	11	237	8.32	.33
	19	1914–1915	3.21	5–22	4.5–6.0	6,892	2,147	1916–1924	9	840	29.08	1.35
	25	1915–1916	11.82	6–32	4.2–6.5	29,654	2,509	1917–1924	8	1,870	19.78	.70
	26	1916–1918	6.48	6–26	4.5–8.7	24,450	3,773	1919–1924	6	1,111	28.58	.76
	64	1919–1920	3.41	6–20		13,224	3,878	1921–1924	4	41	3.01	.08
	65	1919–1920	5.60	5–20		11,907	2,126	1921–1924	4	458	20.45	.96
	87	1919–1921	7.98	6–32	4.3–9.4	44,778	5,611	1922–1925	4	827	25.91	.46
Total or average			47.78			147,466	[3] 3,010			6,897	[3] 19.72	[3] .78
Clay	7	1909 [4]	2.6	[5] 20		4,761	1,831	1921–1925	4½	227	19.40	1.06
	10	1910 [4]	7.6	[5] 24		15,389	2,025	1921–1925	4½	38	1.11	.05
	11	1910 [4]	2.25	[5] 12		2,621	1,165	1921–1925	4½	3	.30	.03
	23	1913 [4]	6.	[5] 26		10,490	1,748	1921–1925	4½	102	3.78	.22
	30	1915 [4]	3.5	[5] 20		5,466	1,56[illegible]	1921–1925	4½	20	1.27	.08
	31	1915 [4]	2.36	[5] 18		3,064	1,298	1921–1925	4½	11	1.04	.08
	32	1915 [4]	3.72	[5] 38		40,225	10,813	1921–1925	4½	675	40.32	.37
	34	1915 [4]	2.4	[5] 22		6,228	2,595	1921–1925	4½	5	.46	.02
	38	1915 [4]	4.8	[5] 22		7,034	1,465	1921–1925	4½	91	4.21	.29
	39	1915 [4]	3.1	[5] 18		3,305	1,066	1921–1925	4½	14	1.00	.09
	40	1916 [4]	5.6	[5] 24		16,185	2,890	1921–1925	4½	46	1.83	.06
	41	1916 [4]	10.	[5] 32		19,248	1,925	1921–1925	4½	255	5.67	.29
	45	1916 [4]	3.2	[5] 20		5,143	1,607	1921–1925	4½	15	1.04	.06

[1] Includes for organization, engineering, construction, and administration to completion of construction.
[2] Includes for inspection, labor, materials, and administration subsequent to construction, but omits for principal and interest on bonds and notes.
[3] Computed from the unit costs of the individual districts rather than from total costs for groups.
[4] Year district was established.
[5] Smaller sizes of drains were also used.

TABLE 1.—*Expenditures for maintenance and repair of tile drains in 106 drainage districts in Iowa, Minnesota, Wisconsin, and Illinois*—Continued

State and county	Drainage district No.	Construction period	Drains installed			Cost of district		Maintenance and repairs				
			Length	Sizes	Depth	Total	Per mile	Period		Expenditures		
								Dates	Length	Total	Per year	
Iowa—Continued.			*Miles*	*Inches*	*Feet*	*Dollars*	*Dollars*		*Years*	*Dollars*	*Per mile*	*Per cent of cost*
Clay—Continued	47	1916 [4]	6.4	[5]24		8,338	1,303	1921–1925	4½	67	2.33	0.18
	49	1916 [4]	2.7	[5]18		3,327	1,232	1921–1925	4½	384	31.60	2.56
	58	1917 [4]	3.9	[5]20		7,720	1,979	1921–1925	4½	5	.28	.01
	62	1917 [4]	2.5	[5]15		4,078	1,631	1921–1925	4½	42	3.73	.23
	63	1917 [4]	2.	[5]20		4,994	2,497	1921–1925	4½	50	6.56	.26
Total or average			74.63			167,616	[3]2,257			2,050	[3]7.00	[3].33
Hamilton	124, Bear Creek	1912–1913	3.78	6–24	4.2–10.0	11,405	3,017	1914–1924	11	543	13.06	.43
	125, Holdengrapher	1912–1913	4.25	6–22	4.7–7.8	8,585	2,020	1915–1924	11	238	5.09	.25
	136, Green	1912–1914	7.62	6–33	4.0–10.0	22,452	2,946	1915–1924	10	1,536	20.16	.68
	137, Alvord	1912–1914	5.79	10–34	4.5–9.5	37,776	6,524	1915–1924	10	16	.28	0
	147, Cass Township	1913–1914	3.93	7–26	5.5–9.0	10,915	2,777	1915–1924	10	2,531	64.40	2.32
	9, Johnson [6]	1907–1908	.63	12–16	5.5–7.2	2,012	3,194	1909–1923	15	None.	0	0
Total or average			26.00			93,145	[3]3,413			4,864	[3]17.17	[3].61
Kossuth	78 [6]	1913–1917	7.64	8–26	4.0–8.0	23,468	3,072	1918–1924	7	10,341	193.36	6.29
	102	1914 [4]	5.42	6–24		18,926	3,492	1920–1924	5	3,217	118.71	3.40
	103	1914 [4]	5.16	6–28		17,087	3,311	1920–1924	5	26	1.01	.03
	105	1914 [4]	15.16	6–36		49,518	3,266	1920–1924	5	1,371	18.09	.55
	108	1915–1917	6.90	6–32		30,893	4,477	1920–1924	5	1,440	41.74	.93
	110	1915–1917	17.71	6–36		70,500	3,981	1920–1924	5	1,172	13.24	.33
	111	1915 [4]	3.45	6–22		7,437	2,156	1920–1924	5	918	53.22	2.47
	112	1915	1.14	10–18		2,820	2,474	1920–1924	5	33	5.79	.23
	113	1915	1.13	6–14		1,502	1,329	1920–1924	5	24	4.25	.32
	120	1915–1916	4.46	6–24	3.9–7.9	8,631	1,935	1920–1924	5	1,277	57.26	2.96
	121	1916–1919	14.44	6–34	3.3–10.1	40,043	2,773	1920–1924	5	350	4.85	.17
	125	1916–1917	6.36	6–24	4.0–8.2	15,160	2,384	1920–1924	5	1,034	32.52	1.36
	126	1916–1917	7.06	8–32	4.3–8.6	22,683	3,213	1920–1924	5	317	8.98	.28
	127	1916	4.98	8–26	4.3–7.4	15,434	3,099	1920–1924	5	335	13.45	.43
	128	1916	2.00	8–22	4.1–5.6	5,523	2,762	1920–1924	5	None.	0	0
	130	1917	1.68	12–18	5.1–5.7	4,366	2,599	1920–1924	5	9	1.07	.04
	134	1916 [4]	5.53	6–26	6.3–7.1	17,201	3,110	1920–1924	5	6	.22	.01
	137	1916	3.98	6–20		9,578	2,407	1920–1924	5	4	.20	.01
	138	1916	3.75	6–24		8,854	2,361	1920–1924	5	18	.96	.04
	139	1916	5.71	6–28		8,854	1,551	1920–1924	5	482	16.88	1.09
	141	1916	3.81	5–26		8,082	2,121	1920–1924	5	67	3.52	.17
	143	1917	1.57	8–22		4,389	2,796	1920–1924	5	1,084	138.09	4.94

Kossuth—Continued	144	1917	1.91	8–22		5,517	2,888	1920–1924	5	84	8.80	.30
	147	1917 [4]	2.43	6–26		8,413	3,462	1920–1924	5	116	9.55	.28
	135	1916	11.17	6–38		43,382	3,884	1920–1924	5	11	.20	.01
	140	1916	1.50	6–14		2,859	1,906	1920–1924	5	208	27.73	1.45
Total or average			146.05			451,120	[3] 2,800			23,944	[3] 29.76	[3] 1.08
Story	21, Grant Township	1909–1910	0.8	16–18		2,387	2,984	1911–1924	14	279	24.91	.83
	35, Grant Township	1910	2.4	8–18		3,573	1,489	1911–1924	14	120	3.84	.26
	78, Grant Township	1917–1918	2.0	6–24		5,282	2,641	1919–1924	6	31	2.58	.10
	84, Grant Township	1918	2.5	5–22		6,071	2,428	1919–1924	6	417	27.80	1.14
	26, Warren Township	1910	.25	12–12		535	2,140	1911–1924	14	None.	0.	0
	54, Warren Township	1913–1915	5.5	8–28		18,202	3,309	1915–1924	10	79	1.44	.04
	29, Howard Township	1909–1910	3.5	10–22		14,909	4,260	1912–1924	13	542	11.91	.28
	32, Milford Township [5]	1912–1914	12.0	8–36		51,312	4,276	1915–1924	10	1,385	11.54	.27
Total or average			28.95			102,271	[3] 2,941			2,862	[3] 10.50	[3] .36
Webster	47	1908–1911	6.39	6–28		19,981	3,127	1912–1924	13	708	8.52	.27
	151	1912–1914	7.92	6–36	3.4–9.1	38,386	4,847	1915–1924	10	1,292	16.31	.34
	152	1912	.58	12–14	3.9–6.6	1,163	2,005	1913–1924	12	None.	0.	0
	153	1912	1.16	6–18		2,667	2,299	1913–1924	12	41	2.95	.13
	154	1913–1914	1.82	8–20	4.6–7.7	4,093	2,249	1915–1924	10	6	.33	.01
	156	1916–1917	1.15	8–20	6.0–10.1	6,824	5,934	1918–1924	7	448	55.65	.94
	157	1912	1.17	5–18	4.0–6.3	1,400	1,197	1914–1924	11	31	2.41	.20
	158	1912–1913	2.15	5–18	4.0–7.6	2,701	1,256	1914–1924	11	None.	0.	0
	160	1913–1914	3.50	8–30	4.3–6.7	12,883	3,681	1915–1924	10	523	14.94	.41
	176	1914–1916	6.07	5–28	3.8–8.0	20,149	3,319	1918–1925	8	711	14.64	.44
	189	1918–1920	8.56	6–36	5.0–17.2	60,783	7,101	1921–1924	4	12	.35	0
Total or average			40.47			171,030	[3] 3,365			3,772	[3] 10.55	[3] .25
Wright	81	1913	2.29	12–22	5.2–7.5	8,579	3,746	1914–1924	11	13	0.52	.01
	88	1913	2.85	12–24	5.1–9.5	10,607	3,722	1916–1924	9	7	.27	.01
	105	1914–1916	4.52	8–26	4.2–7.5	11,527	2,550	1917–1924	8	340	9.40	.37
	107 [6]	1915–1917	13.03	10–32	4.4–8.4	59,995	4,604	1921–1924	4	455	8.73	.19
Total or average			22.69			90,708	[3] 3,656			815	[3] 4.73	[3] .14
State total or average			420.74			1,367,638	[3] 2,962			46,984	[3] 16.15	[3] .59
Minnesota:												
Blue Earth	County, 33	1914	2	8–18		5,298	2,649	1917–1924	8	290	18.12	.68
	County, 35	1915	9	12–36		48,467	5,385	1917–1924	8	3,694	51.30	.95
	County, 47	1917–1920				42,200		1921–1924	4	1,600		.95
	Judicial, 22	1917–1918	4	8–28		14,375	3,594	1920–1924	5	131	6.55	.18
Total or average			15			110,340	[3] 3,876			5,715	[3] 25.32	[3] .69

[3] Computed from the unit costs of the individual districts rather than from total costs for groups.
[4] Year district was established.
[5] Smaller sizes of drains were also used.
[6] Data shown omit figures for open ditches constructed by this district.

TABLE 1.—*Expenditures for maintenance and repair of tile drains in 106 drainage districts in Iowa, Minnesota, Wisconsin, and Illinois*—Continued

State and county	Drainage district No.	Construction period	Drains installed: Length	Drains installed: Sizes	Drains installed: Depth	Cost of district: Total	Cost of district: Per mile	Maintenance and repairs: Period: Dates	Maintenance and repairs: Period: Length	Maintenance and repairs: Expenditures: Total	Expenditures: Per year: Per mile	Expenditures: Per year: Per cent of cost
			Miles	*Inches*	*Feet*	*Dollars*	*Dollars*		*Years*	*Dollars*	*Per mile*	*Per cent of cost*
Minnesota—Continued.												
Brown	County, 22	1915[4]	3.0	[5]15		4,197	1,399	1920–1924	5	20	1.33	0.09
	County, 30	1916[4]	4.4	[5]16		15,418	3,504	1920–1924	9	9	.23	.007
	County, 35	1916[4]	3.4	[5]12		4,534	1,334	1920–1924	5	383	22.53	1.69
	County, 38	1917[4]	8.0	[5]22		22,303	2,788	1920–1924	5	51	1.28	.05
Total or average			18.8			46,452	[3]2,256			463	[3]6.34	[3].46
Lyon	County, 11	1912–1914	7.18	5–20		9,863	1,374	1915–1924	10	2,616	36.43	2.65
	County, 38	1917–1918	6.28	5–24		17,138	2,729	1920–1924	5	33	1.05	.04
	Judicial, 10	1914–1915	5.26	5–12		3,797	722	1916–1924	9	454	9.59	1.33
Lyon and Yellow Medicine.	Judicial, 16	1917–1919	12.34	6–30		45,671	3,701	1920–1924	5	431	6.99	.19
Total or average			31.06			76,469	[3]2,132			3,534	[3]13.52	[3]1.05
Redwood	County 22[6]	1917[4]	34.0	6–30		155,109	4,562	1920–1924	5	None.	0	0
State total or average			98.86			388,370	[3]2,812			9,712	[3]12.95	[3].68
Wisconsin:												
Dane	Farm drainage 1	1920–1921	1.39	6–18		4,731	3,404	1922–1924	3	732	175.54	5.16
	Farm drainage 3	1920–1921	1.68	[5]12		4,617	2,748	1922–1924	3	178	35.32	1.29
Kenosha and Racine	Yorkville and Raymond extension[6]	1913–1915	1.86	[5]18		3,042	1,635	1917–1923	7	610	46.85	2.87
State total or average			4.93			12,390	[3]2,596			1,520	[3]85.90	[3]3.11
Illinois:												
Champaign	Camp Creek special (10 subdistricts)	1907–1910	19.75	8–24		53,366	2,702	1918–1922	5	644	6.52	.24
Champaign and Douglas	Okaw (subdistricts 1 to 13)	1903–1910	23.5	8–24		35,318	1,503	1913–1922	10	1,135	4.83	.32
Ford	Subdistrict 1 of Hillsbury Slough special	1898[4]	2.1	8–22		6,069	2,890	1914–1922	9	49	2.59	.09
State total or average			45.35			94,753	[3]2,365			1,828	[3]4.65	[3].22

[3] Computed from the unit costs of the individual districts rather than from total costs for groups.
[4] Year district was established.
[5] Smaller sizes of drains were also used.
[6] Data shown omit figures for open ditches constructed by this district.

Table 2.—*Expenditures for maintenance and repair of open ditches in 18 drainage districts in Iowa, Minnesota, Wisconsin, and Illinois*

State and county	Drainage district	Construction period	Open ditches installed: Length	Open ditches installed: Bottom width	Open ditches installed: Depth	Cost of district[1]: Total	Cost of district[1]: Per mile	Maintenance and repairs: Period: Dates	Maintenance and repairs: Period: Length	Maintenance and repairs: Expenditures[2]: Total	Expenditures[2]: Per year: Per mile	Expenditures[2]: Per year: Per cent of cost
			Miles	*Feet*	*Feet*	*Dollars*	*Dollars*		*Years*	*Dollars*	*Per mile*	*Per cent of cost*
Iowa:												
Hamilton	Johnson, No. 9[3]	1906–1907	11.55	4–7	5.6–11.1	21,063	1,824	1908–1923	16	24,240	$131.22	7.19
Hamilton	Squaw Creek, No. 47	1908–1910	12.92	4–18		41,237	3,192	1911–1923	13	34,436	205.03	6.42
Story	Grant Township, No. 5	1903–1909	5.96	3–4		23,175	3,888	1910–1924	15	11,408	127.61	3.28
Story	Milford Township, No. 32[3]	1912	3.4	4		13,358	3,929	1913–1917	5	3,565	200.71	5.34
Kossuth	No. 78[3]	1913	2.24	8	7.8	8,688	3,879	1914–1921	8	9,105	508.09	13.10
Wright	No. 14	1906–1909	9.74	5–16	7	40,000	4,107	1910–1920	11	15,939	148.77	3.62
Wright	No. 107[3]	1915	6.99	[4] 24	7–6	29,385	4,204	1916–1923	8	3,688	65.95	1.57
Total or average			52.80			176,906	[5] 3,575			102,300	[5] 199.48	[5] 5.79
Minnesota:												
Blue Earth	County No. 5	1901	20	[4] 20		10,989	549	1917–1924	8	9,075	56.72	10.33
Brown	County No. 10	1906[6]	6.5	[4] 6		5,393	830	1920–1924	5	544	16.74	2.02
Brown	County No. 12	1907[6]	8.6	[4] 5		9,307	1,082	1920–1924	5	409	9.61	.88
Brown	County No. 13	1908[6]	10.9	[4] 10		13,331	1,223	1920–1924	5	104	1.91	.16
Lyon and Yellow Medicine	Judicial No. 2	1907–1908	7.83	4–8	4	8,403	1,073	1910–1920	11	582	6.76	.63
Redwood	County No. 22[3]	1917[6]	7.5	[4] 10	4½	35,880	4,784	1920–1924	5	6,000	160.00	3.34
Total or average			61.33			83,303	[5] 1,590			16,714	[5] 41.94	[5] 2.89
Wisconsin:		1912–1914										
Dane	Koshkonong-Mud Creek	1913–1915	26.7	2–26	4–6	47,108	1,764	1916–1924	9	4,617	19.21	1.09
Kenosha and Racine	Yorkville and Raymond extension.[3]		10.44	3–20		17,227	1,650	1917–1923	7	1,016	13.90	.84
Total or average			37.14			64,335	[5] 1,707			5,633	[5] 16.56	[5] .96

[1] Includes for organization, engineering, construction, and administration to completion of construction.
[2] Includes for inspection, labor, materials, and administration subsequent to construction, but omits for principal and interest on bonds and notes.
[3] Data shown omit figures for tile drains constructed by this district.
[4] Ditches with narrower bottom widths were also used.
[5] Computed from the unit costs of the individual districts rather than from total costs for groups.
[6] Year district was established.

TABLE 2.—*Expenditures for maintenance and repair of open ditches in 18 drainage districts in Iowa, Minnesota, Wisconsin, and Illinois*—Continued

State and county	Drainage area	Construction period	Open ditches installed			Cost of district		Maintenance and repairs				
								Period		Expenditures		
			Length	Bottom width	Depth	Total	Per mile	Dates	Length	Total	Per year	
											Per mile	Per cent of cost
Illinois:			*Miles*	*Feet*	*Feet*	*Dollars*	*Dollars*		*Years*	*Dollars*		
Champaign and Douglas	Okaw (omitting for subdistricts).	1902 [6]	12.0	[4] 24		30,839	2,570	1913–1922	10	9,040	75.33	2.93
Champaign and Ford	Hillsbury Slough special (Main and subdistricts 2, 3, 4).	1898 [6]	15.84	6–10	4–8	36,266	2,290	1914–1922	9	2,809	20.34	.89
Macon	Stevens Creek special	1884–1887	13.15	[4] 8		17,361	1,320	1890–1924	35	19,445	42.25	3.20
Total or average			40.99			84,466	[5] 2,060			31,384	[5] 45.97	[5] 2.34

[4] Ditches with narrower bottom widths were also used.
[5] Computed from the unit costs of the individual districts rather than from total costs for groups.
[6] Year district was established.

For all these districts, the average annual expenditure has been about 3.7 per cent of the installation costs, and for those in Iowa about 5.8 per cent. If the average annual expense of maintaining open ditches in fairly effective condition is 5 per cent of the installation cost, this is about equivalent to an increase of 75 per cent in that cost if loans bear interest at 6¾ per cent.

COMPARATIVE COSTS OF TILE AND OPEN-DITCH DRAINAGE

SIZE OF DRAINS

Computations were made to determine the sizes of open ditches having capacities comparable to those of tile drains of 24 to 48 inches diameter. Flow in open ditches was computed with the Chezy-Kutter formula, using a roughness coefficient value of 0.040 which corresponds with the recommendations of Ramser.[1] Flow in tile drains was computed with the Yarnell formula, $V = 138\ R^{2/3}\ S^{1/2}$, which gives results practically the same as given by the Chezy-Kutter formula with $n = 0.011$, for these tile sizes. It was thus determined that the tile drains have no greater capacity than ditches of 1 to 1 side slopes with bottom width and depth of flow equal to the diameter of the tile.

BASES OF ESTIMATING FOR COMPARISON

The prices paid for draintile have varied widely, both with time and with location. They fluctuate according to supply and demand, and are considerably affected by the amount of competitive bidding for the contracts. The costs of labor for installing the tile and of excavation for open ditches vary likewise but not necessarily in the same direction as the prices for tile. In estimating the installation cost of drains for making the comparisons in the following pages, prices have been assumed for the purchase of tile as shown in Table 3; for the labor of digging the trenches, laying the tile, and back filling as in Table 4; for excavating open ditches, 12 cents per cubic yard; and for damages $100 per acre for the land taken for right of way. Tables 3 and 4 represent about average prices in 1922 to 1925, as determined from a considerable number of contracts let in Iowa during that period.

TABLE 3.—*Prices for draintile delivered on site of work* [a]

Tile diameter	Cost per 1,000 feet	Tile diameter	Cost per 1,000 feet	Tile diameter	Cost per 1,000 feet
Inches	*Dollars*	*Inches*	*Dollars*	*Inches*	*Dollars*
15	295	27	1,060	39	2,285
18	440	30	1,310	42	2,700
21	620	33	1,590	45	3,175
24	830	36	1,900	48	3,700

[a] Based on contracts let in Iowa in 1922–1925.

[1] RAMSER, C. E. FLOW OF WATER IN DRAINAGE CHANNELS. THE RESULTS OF EXPERIMENTS TO DETERMINE THE ROUGHNESS COEFFICIENT n IN KUTTER'S FORMULA. U. S. Dept. Agr. Tech. Bul. 129, 102 p., illus. 1929.

67751—31——2

TABLE 4.—*Prices for trenching, laying tile, and back filling*[1] *per 1,000 feet of drain*

Depth of trench	Cost for size of tile (inside diameter, in inches) indicated											
	15	18	21	24	27	30	33	36	39	42	45	48
	Dolls.	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
3 feet	85	110	125									
4 feet	100	125	155	175	200							
5 feet	135	165	195	220	245	265	290	315	340			
6 feet	180	210	240	270	300	330	360	390	410	440	465	490
7 feet	240	275	315	350	390	420	455	490	520	550	585	620
8 feet	310	355	400	440	485	525	565	600	640	675	715	755
9 feet	385	440	495	540	590	635	675	720	765	805	850	890
10 feet	470	530	590	645	700	750	800	850	900	945	990	1,030
11 feet	560	630	695	760	820	875	930	980	1,035	1,080	1,130	1,180
12 feet	605	740	815	880	955	1,010	1,070	1,130	1,175	1,230	1,280	1,340
13 feet	775	855	935	1,010	1,080	1,150	1,210	1,270	1,325	1,380	1,440	1,500
14 feet	890	980	1,070	1,150	1,225	1,290	1,350	1,420	1,480	1,540	1,600	1,660
15 feet	1,000	1,100	1,200	1,300	1,375	1,450	1,500	1,575	1,650	1,700	1,750	1,800

[1] Based on contracts let in Iowa in 1922–1925.

The installation cost of a drainage district constructing only tile drains includes, besides the principal items for purchase of tile and labor of installation covered by Tables 3 and 4, an appreciable expense for organization, administration, and engineering. The amount of these incidental expenses was determined for a considerable number of the drainage districts shown in Table 1 and were found to constitute from 5 to 25 per cent of the cost of tile and labor; for most of the districts in Iowa, the incidental expenses were less than 10 per cent. They have been computed as 8 per cent in making the comparisons that follow.

Practice as to the minimum size of open ditch to be constructed varies with local physical conditions and with the judgment of the designing engineer. Bottom widths are probably never designed less than 4 feet, commonly not less than 6 feet, and for some situations not less than 8 feet. Side slopes usually are specified to be 1, 1¼, 1½ horizontal to 1 vertical. Minimum depths for construction are seldom assumed less than 6 feet, often not less than 8 feet. Further, ditches to be used as outlets for tile drains are generally designed to be 2 to 3 feet deeper than the bottom of the tile. For making the comparisons of cost, therefore, each size of tile has been compared with a ditch of 6 feet bottom width, 3 feet deeper than the tile, having side slopes of 1½ to 1. For tile depths of 7 feet and less comparison is shown also with ditches of 4 feet bottom width, 2 feet deeper than the tile, having 1½ to 1 side slopes.

The principal items in the installation cost of a district constructing only open ditches are the excavation of the ditches and damages allowed owners for land occupied by the ditches and waste banks. Right of way has been computed herein as 5 per cent greater than required for piling one-half the excavated material on each side of the ditch, leaving clear berms of 8 feet—but not less than half the depth of the ditch—between the waste banks and the edges of the ditch and giving the waste banks side slopes of 1 to 1. Damages have been computed as the equivalent of purchasing this right of way at $100 per acre. The incidental costs, comprising all expenses for installation except excavation and damages, have been estimated at 15 per cent of those two items.

CAPITALIZED TOTAL COSTS

The capitalized total costs of the tile drains and of the open ditches have been computed by adding to the installation costs, estimated as above described, the equivalent investments for maintenance (p. 2) amounting to 10 per cent and 75 per cent, respectively, of the installation costs. The capitalized total cost of a tile drain is thus computed as 1.188 times the cost of tile plus labor for trenching, laying, and back filling, while the capitalized total cost of an open ditch is computed as 2.0125 times the cost of excavation plus damages. Tables 5 and 6 show these total capitalized costs, per 1,000 feet for drains of 15-inch to 48-inch tile at 3 to 15 feet deep and for the open ditches that might be substituted in a drainage system.

TABLE 5.—*Capitalized total cost of tile drains, including maintenance, per 1,000 feet length*

Depth of trench	Cost for size of tile (inside diameter, in inches) indicated											
	15	18	21	24	27	30	33	36	39	42	45	48
	Dolls.	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
3 feet	452	653	885									
4 feet	470	671	921	1,194	1,497							
5 feet	511	719	968	1,247	1,550	1,871	2,233	2,631	3,118			
6 feet	565	772	1,022	1,307	1,616	1,948	2,317	2,721	3,202	3,730	4,324	4,978
7 feet	636	849	1,111	1,402	1,723	2,055	2,429	2,839	3,332	3,861	4,467	5,132
8 feet	719	944	1,212	1,509	1,835	2,180	2,560	2,970	3,475	4,010	4,621	5,292
9 feet	808	1,046	1,325	1,628	1,960	2,311	2,391	3,113	3,623	4,164	4,782	5,453
10 feet	909	1,152	1,437	1,752	2,091	2,447	2,839	3,267	3,784	4,330	4,948	5,619
12 feet	1,140	1,402	1,705	2,031	2,394	2,756	3,160	3,600	4,110	4,669	5,293	5,988
15 feet	1,539	1,830	2,162	2,530	2,893	3,279	3,671	4,128	4,676	5,227	5,851	6,534

TABLE 6.—*Capitalized total cost of open ditches, including maintenance, per 1,000 feet length*

4-FOOT BOTTOM WIDTH;[1] SIDE SLOPES 1½ TO 1

Depth of cut	Excavation	Right-of-way width	Cost	Depth of cut	Excavation	Right-of-way width	Cost
	Cubic yards	*Feet*	*Dollars*		*Cubic yards*	*Feet*	*Dollars*
5 feet	2,130	59	789	8 feet	4,740	80	1,515
6 feet	2,890	66	1,004	9 feet	5,830	87	1,811
7 feet	3,760	73	1,246				

6-FOOT BOTTOM WIDTH; SIDE SLOPES 1½ TO 1

Depth of cut	Excavation	Right-of-way width	Cost	Depth of cut	Excavation	Right-of-way width	Cost
	Cubic yards	*Feet*	*Dollars*		*Cubic yards*	*Feet*	*Dollars*
5 feet				12 feet	10,670	111	3,089
6 feet	3,340	70	1,131	13 feet	12,280	119	3,512
7 feet	4,280	77	1,391	14 feet	14,000	125	3,959
8 feet	5,340	85	1,673	15 feet	15,840	132	4,436
9 feet	6,500	91	1,990	16 feet	17,780	139	4,939
10 feet	7,780	98	2,332	17 feet	19,840	146	5,468
11 feet	9,170	105	2,699	18 feet	22,000	154	6,025

[1] The Department of Agriculture does not favor the use of 4-foot bottom ditches more than about 8 feet deep.

Comparison of these costs is shown graphically in Figure 1.

The intersections of the curves mark the depths where either tile or open ditch may be used with equal economy, if the costs are as indicated on page 11. The figure shows 24-inch tile as becoming economical at a depth of about 5 feet as compared with the ditch of 4-foot bottom 2 feet deeper than the tile, and at all practicable depths when compared with the 6-foot ditch. The 36-inch tile

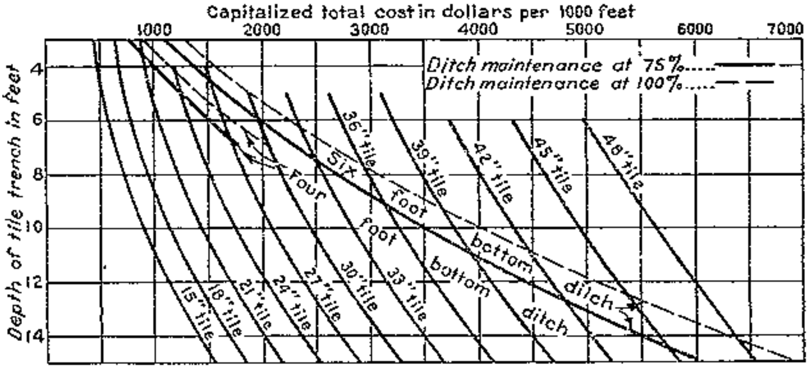


FIGURE 1.—Capitalized total cost of tile drains (Table 5) compared with capitalized total cost of open ditches of 4-foot bottom width 2 feet deeper than the tile, and of 6-foot bottom width 3 feet deeper than the tile (Table 6)

would be economical at about 9 feet. At the costs stated in Tables 5 and 6, 48-inch tile would not be economical at less than 16 feet, at which depth stronger and more costly tile or expensive cradling doubtless would be required to prevent crushing of the drain by the weight of the back fill.

EFFECT OF VARIATIONS IN PRICES

The comparisons in Figure 1 should be recognized as illustrative, rather than as final determinations of the depths at which tile of various sizes become economical. Prices of materials and labor vary, as before stated; land values and other local conditions affect

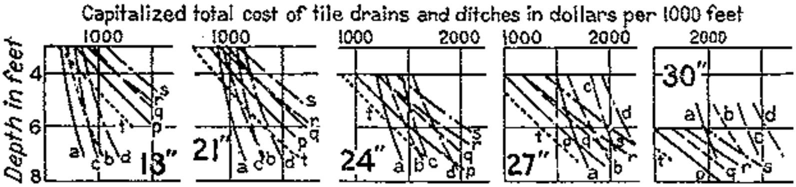


FIGURE 2.—Effect upon capitalized total costs of tile drains of 18 to 30 inches diameter, and of open ditches of 4-foot bottom 2 feet deeper than the tile, of certain variations in prices from those used in Tables 5 and 6: *a*, Cost as per Table 5; *b*, labor prices increased 50 per cent; *c*, tile prices increased 25 per cent; *d*, both labor and tile prices increased, as above stated; *p*, cost as per Table 6; *q*, damages increased 50 per cent; *r*, excavation price increased 25 per cent; *s*, both damages and excavation prices increased, as above stated; *t*, damages decreased 50 per cent

the amount of damages paid for land occupied by an open ditch; and many circumstances influence the total of incidental expenses in the installation cost of a drain. The computations of equivalent investment for maintenance are based upon a relatively small amount of data that vary greatly, and opinions differ as to whether adequate, regular maintenance would cost less or more than the average that has been expended. The effect of capitalizing maintenance of the open ditches at 100 per cent instead of 75 per cent of the installation cost, upon the comparisons made in the preceding paragraph, is indicated in Figure 1.

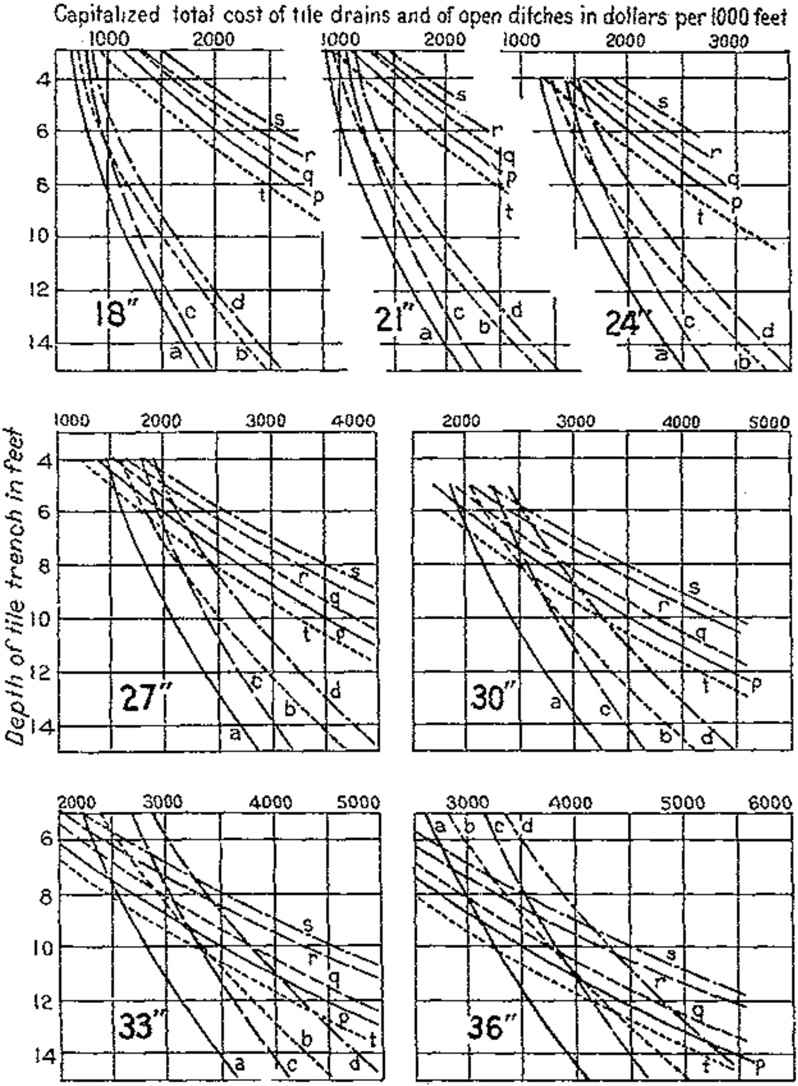


FIGURE 3.—Effect upon capitalized total costs of tile drains of 18 to 36 inches diameter, and of open ditches of 6-foot bottom 3 feet deeper than the tile, of certain variations in prices from those used in Tables 5 and 6: *a*, Cost as per Table 5; *b*, labor prices increased 50 per cent; *c*, tile prices increased 25 per cent; *d*, both labor and tile prices increased, as above stated; *p*, cost as per Table 6; *q*, damages increased 60 per cent; *r*, excavation price increased 25 per cent; *s*, both damages and excavation prices increased, as above stated; *t*, damages decreased 50 per cent

In order to show the effect of variation in prices of tile, tile labor, open-ditch excavation, and damages for right of way upon the relative economy of tile drains and open ditches, Figures 2, 3, and 4 have

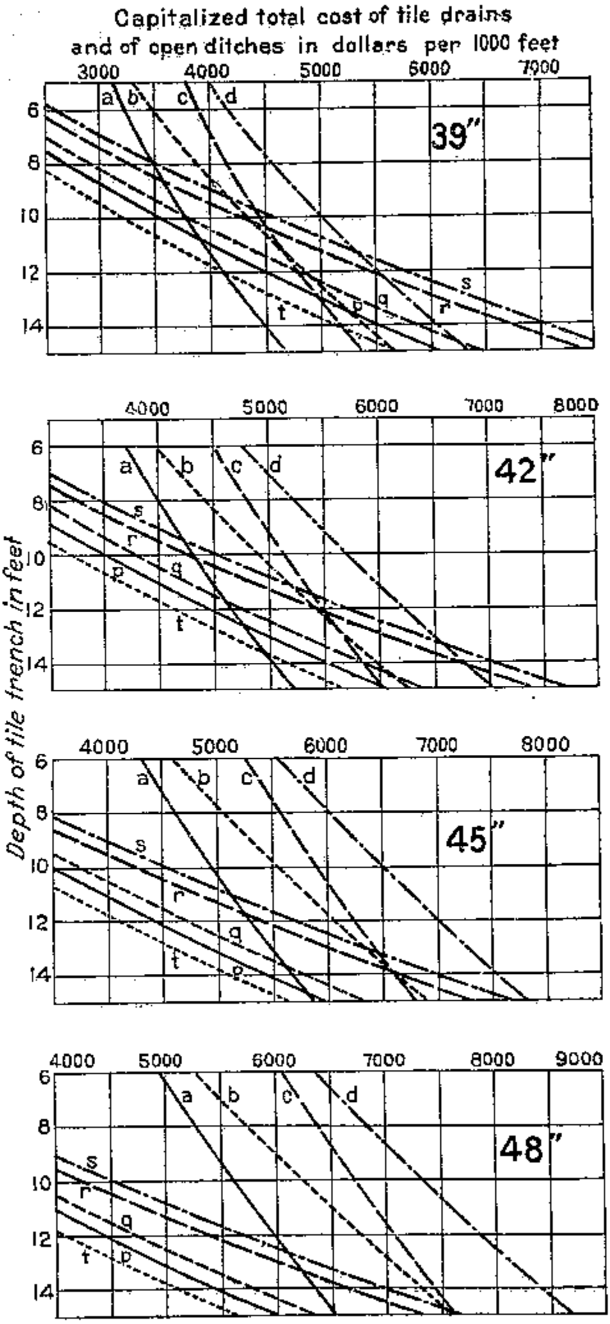


FIGURE 4.—Effect upon capitalized total costs of tile drains of 39 to 48 inches diameter, and of open ditches of 6-foot bottom 3 feet deeper than the tile, of certain variations in prices from those used in Tables 5 and 6: *a*, Cost as per Table 5; *b*, labor prices increased 50 per cent; *c*, tile prices increased 25 per cent; *d*, both labor and tile prices increased, as above stated; *p*, cost as per Table 6; *q*, damages increased 50 per cent; *r*, excavation price increased 25 per cent; *s*, both damages and excavation prices increased as above stated; *t*, damages decreased 50 per cent

been prepared. Each figure shows graphically, for different sizes of tile, the effect upon the capitalized total cost of certain variations from the prices used in preparing Tables 5 and 6. The percentages for incidental installation costs and for maintenance have been applied to the increases in base prices.

Comparison of capitalized total costs at other prices than those used in the figures may be made by interpolation between the curves. An increase or decrease of one-half in the estimate of incidentals would entail a change in the capitalized total cost of 3.7 per cent for the tile drains or 6.5 per cent for the open ditches, while an increase or decrease of one-third in the equivalent investment for maintenance would cause a change in the capitalized total cost of 3 per cent for the tile drain. or 14.3 per cent for the open ditches.

ECONOMICAL RELATION OF CONSTRUCTION COSTS

The capitalized total cost of a drain may be expressed as

$$T = C(1+I)(1+M),$$

in which T = the capitalized total cost;

C = the construction cost—the cost of tile plus trenching, laying, and back filling, or the cost of open ditch excavation plus damages;[2]

I = the incidental expenses—all items for installation not included in the construction cost—expressed as a fraction of the construction cost C;

M = the equivalent investment for maintenance, expressed as a fraction of the total installation cost, $C(1+I)$.

The two types of drain are of equal economy when the capitalized total investments are the same; that is, using the single accent (′) for designating the tile drain and the double accent (″) for the open ditch, they are of equal economy when $T' = T''$, or

$$C'(1+I')(1+M') = C''(1+I'')(1+M'').$$

This condition obtains at the intersections of the curves in Figures 1, 2, 3, and 4.

Ultimate economy would require that tile be used when

$$\frac{C'}{C''} < \frac{(1+I'')(1+M'')}{(1+I')(1+M')}$$

and that the open ditch be used when

$$\frac{C'}{C''} > \frac{(1+I'')(1+M'')}{(1+I')(1+M')}$$

Tables 5 and 6 are computed with the values $I' = 0.08$, $M' = 0.10$, $I'' = 0.15$, $M'' = 0.75$. Then $T' = T''$ when $\frac{C'}{C''} = 1.69$; that is, drainage with tile is economical when the construction cost (tile plus labor) is two-thirds greater than the construction cost (excavation plus damages) for an open ditch.

Figure 1 shows also a comparison of the capitalized total costs using a larger equivalent investment for maintenance of the open ditches, the values substituted in the equation being $I' = 0.08$, $M' = 0.10$, $I'' = 0.15$, $M'' = 1.00$.

[2] The inclusion of other items such as outlet protection and surface inlets for tile or bridges for open ditches, when of considerable amount, would tend to make the estimate of capitalized total cost for any particular drain somewhat more accurate.

Then $T' = T''$ when $\frac{C'}{C''} = 1.94$, indicating that the tile is economical even when the construction cost is practically double that for the open ditch.

In the case of any particular drainage district, various items of cost may vary considerably from those used in the foregoing computations. It seems evident, however, that when the construction cost will be three-fourths greater for a tile drain than for an open ditch, the economy of the former is doubtful and should at least be studied carefully; and when the tile will cost double the other, the open ditch almost certainly will be cheaper in the long run.

USE OF GRAPHS AND FORMULAS

The following example shows how Figures 1, 2, 3, and 4, or the formula on page 15, may be utilized in determining the more economical kind of drain to use in any particular instance.

Let it be assumed that the landowners in a proposed drainage district wish to know, before voting for construction of the drains, just what combination of tile and open ditches will provide drainage for the lowest ultimate cost. The preferred construction comprises tile up to 39 inches in diameter. Soil, topographic, and climatic conditions make it advisable that open-ditch drains be not less than 6 feet in bottom width, at least 3 feet deeper than the outlets of tile branches, and have side slopes 1½ to 1 as in Table 6. For the 30-inch and larger tile, the average depths will be about 7½ feet. Let it be assumed further that prices for the larger sizes of tile average about 20 per cent more than shown in Table 3; that prices for trenching, laying tile, and back filling are about 10 per cent less than shown in Table 4; that damages to farms crossed by an open ditch would be $125 per acre taken for right of way, which is 25 per cent more than those used in preparing Table 6; and that the other costs are estimated at the same rates used in computing Tables 5 and 6, namely, open-ditch excavation at 12 cents per cubic yard, incidentals at 8 per cent for tile drains and 15 per cent for open ditches, and capitalized maintenance at 10 per cent for tile drains and 75 per cent for open ditches.

Inspection of Figure 1 shows that, at the prices used in computing Tables 5 and 6, 33-inch tile 7½ feet deep and the corresponding 6-foot bottom open ditch are approximately equal in capitalized total cost. Therefore study is made of the curves for the 33-inch tile in Figure 3. (For minimum open-ditch specifications other than used herein, suitable curves can be plotted.)

The distance between curves *a* and *c* in Figure 3 represents a variation of 25 per cent in prices for tile, and the distance between curves *a* and *b* represents a variation of 50 per cent in prices for trenching, laying, and back filling. (These distances are to be measured horizontally along lines of uniform depth.) Interpolating for 20 per cent increase in tile prices and 10 per cent decrease in labor prices from those used for Table 5 and curve *a* indicates, for 7½ feet depth, a total capitalized cost of about $2,800 per 1,000 feet for the 33-inch tile. The distance between curves *p* and *q* represents a variation of 50 per cent in the cost of damages for an open ditch. Interpolating for an increase of 25 per cent in damages from those used for Table

6 and curve *p* indicates for 7½ feet depth of tile trench a total capitalized cost of about $2,650 per 1,000 feet for the corresponding open ditch. Thus the open ditch is shown as approximately $150 per 1,000 feet cheaper than the 33-inch tile. The difference in favor of the open ditch will increase with the size of tile, at the same depth.

The curves for 30-inch tile in Figure 3 show that, for a tile depth of 7½ feet, the capitalized total cost of the open ditch would be greater than the cost of a tile drain of that size, at the prices used herein. Therefore 30-inch and smaller tile will be more economical than open ditches, for depths of 7½ feet and more.

The same conclusions as to economical sizes of tile are shown by computations with the formula stated on page 15. For the 33-inch tile 7½ feet deep and the 6-foot bottom ditch 10½ feet deep, the following values are determined from interpolation in Tables 5 and 6:

$$C' = (1{,}590 \times 1.20) + (510 \times 0.90) = 2{,}367$$

$$C'' = (8{,}470 \times 0.12) + \left(\frac{101{,}000}{43{,}560} \times 125\right) = 1{,}306$$

$$(1+I'')(1+M'') = 1.15 \times 1.75 = 2.0125$$

$$(1+I')(1+M') = 1.08 \times 1.10 \times 1.188$$

$$\frac{C'}{C''} = 1.812 > \frac{(1+I'')(1+M'')}{(1+I')(1+M')} = 1.694$$

For 30-inch tile, at the same depth, the comparison is:

$$C' = (1{,}310 \times 1.20) + (470 \times 0.90) = 1{,}995$$

$$C'' = (8{,}470 \times 0.12) + \left(\frac{101{,}000}{43{,}560} \times 125\right) = 1{,}306$$

$$\frac{C'}{C''} = 1.528 < \frac{(1+I'')(1+M'')}{(1+I')(1+M')} = 1.694$$

These results, like the graphs, indicate that the 33-inch tile will be more expensive and the 30-inch tile more economical than the open ditch.

Either of these methods of determining the relative ultimate economy of tile drains or open ditches is quicker and less laborious than computation of the actual capitalized total cost of various sizes of drains, by the formula $T = C\ (1+I)\ (1+M)$ without reference to charts like Figures 1 to 4.

REDUCTION OF MAINTENANCE COST

ADMINISTRATION EXPENSES

For three-fourths of the districts in Iowa and Minnesota listed in Tables 1 and 2, about 9½ per cent of the total maintenance expenditures have been for administration of the districts and inspections of the drains, and about 90½ per cent for labor and materials to clean and repair the drains, both for tile and for open ditches. The data for Illinois and Wisconsin districts seem to indicate that a fourth or more of the maintenance costs are for administration and inspections. The legal fees for preparing and filing routine reports apparently are much greater in Illinois and Wisconsin than in Iowa and Minnesota.

It does not seem probable that a material reduction can be made in the inspection and administration costs, unless by simplifying the procedure of making and filing annual reports in certain States. The frequency of inspecting the drains should not be decreased but in many counties should be increased. Reduction in the annual costs may best be undertaken in matters of design and construction of the drains.

NATURE OF REPAIR WORK ON TILE DRAINS

One of the troubles most frequently encountered in the operation of tile drains is "blow-outs." These result from internal pressure where the lower part of a drain can not discharge the water brought down by the line or lines above. The water forced out loosens the overlying earth, and the return flow when the flood crest has passed displaces the tile and washes in large quantities of earth. Repair of a blow-out ordinarily consists of digging open the drain, cleaning the undisturbed portion, and reconstructing the damaged section on a new bed that in many cases must be of concrete.

In the ground over tile drains holes occur not infrequently, particularly during the first few years after construction. They are caused by surface water flowing down through a loose back fill and wide joints in the drain. For a time the flow through the drain may carry away the soil washed in, but finally tiles become displaced or broken if the injury is not discovered and repaired before actual breakdown occurs. In some instances long lengths of drain have had to be relaid or abandoned.

In a great many districts repairs to the head walls at tile outlets have been required. Some head walls evidently have lacked strength and stability, but many apparently substantial structures have been broken or overturned due to undermining by the discharge from the drain. Joints in the tile line have been opened by settlement of the earth about the head wall, so that water flowing out of those joints has washed away the earth and caused failure of the drain and the wall.

Surface inlets often are a source of trouble. The weight of a vertical column of tile upon the drain causes settlement of the latter. Water entering the joints of the upright pipe or flowing down outside wash in earth to choke the drain and allow displacement of the inlet. Earth and débris are washed in when the screens on the inlets are broken or displaced.

In some instances deep drains have been broken by the weight of earth over them in the trench; in some locations tile of improper quality have failed through the action of certain salts or acids in the soil.

PREVENTING INJURY TO THE DRAINS

Injury to tile drains can be reduced to a minimum, and a large part of repair charges such as shown in Table 1 can be avoided by proper design and construction of the drains. Blow-outs are to be avoided by giving each section of the drain capacity equal to that of all the drains above, keeping the hydraulic gradient everywhere well below the ground surface. Holes or "wash ins" over the drains are to be prevented by fitting the tile closely together; by covering the joints with tarred paper, burlap, or other suitable material where the drain passes through fine, loose sand; and by giving extra support where necessary, as at junctions and through soft ground, to maintain the grade and alignment. Head walls should be of substantial proportions and should be built on firm foundations. They should have aprons and cut-off walls to prevent undermining, and the refilling material about them should be well compacted to hold the drain in place and to prevent percolation of water behind the wall. Surface inlets should be adequately supported against settlement, and surrounded with compacted earth. They should be covered with a good screen fastened in place and should be located where there is little danger of injury from machinery, livestock, or other causes. Inlets of small sewer pipe are said to have been damaged by the lifting effect of frost under the bells. The tile used for the drains should be strong enough and be properly bedded or supported to bear the loads that will come upon them,[3] and of quality suited to the existing conditions.

Good design must be supplemented by good construction to insure satisfactory results. The contract for construction should be clear and definite and should cover all contingencies, including authorization of extra work and payment therefor. No ambiguity should be left as to what constitutes fulfillment of the contract. Continuous and thorough inspection is essential. The importance of adequate inspection during installation of the drains should be fully realized by all drainage district officials, and parsimony in the matter of employing inspectors is the opposite of economy. The cost of a "penny wise and pound foolish" policy in this matter appears in the repair and replacement expenses that may continue over a period of several years.

Tile may be tested at the factory, but each piece should be inspected as it is laid in the trench. The width of the trench below the top of the tile must not exceed the determined maximum, as that width rather than the tile size determines the load upon the drain. Close fitting of the tiles in the drain, smooth and firm connection at the junction of two or more lines, covering of joints through running sand, and preservation of grade and alignment through unstable soils should be obtained without exception. Carelessness in back filling the trenches must not be permitted, for sometimes tile have been broken by falling stones and frozen lumps of earth, and large sods or lumps dumped upon the tile without being well mixed with finer material have many times been the cause of "wash ins" requiring expensive repairs. The inspector's work is not completed until the last bit of refilling has been done over the drain and properly compacted about the outlet head walls and other structures.

ESTIMATING DAMAGES CAUSED BY OPEN DITCHES

In the foregoing comparison of costs of tile drains and open ditches it has necessarily been assumed that the damages allowed to the owners of land taken for right of way or other purposes represent the actual losses to those owners. In the opinion of many drainage district officials, however, the damages awarded have not been adequate. Therefore it seems appropriate to discuss briefly the subject of estimating these damages, although presentation of a formula for computing them is not attempted.

---

[3] The strength requirements and methods of testing of drain tile were published in the following: AMERICAN SOCIETY FOR TESTING MATERIALS. STANDARD SPECIFICATIONS FOR DRAIN TILE. Designation C4-24. A. S. T. M. Standards, 1930 (pt. 2): 249. 1930. Methods of bedding and cradling tile to carry increased loads are described in the following publication: SCHLICK, W. J. SUPPORTING STRENGTH OF DRAIN TILE AND SEWER PIPE UNDER DIFFERENT PIPE-LAYING CONDITIONS. Iowa Engin. Expt. Sta. Bul. 57 (v. 18, no. 46), 66 p., illus. 1920.

COMMON METHODS OF APPRAISING DAMAGES

The method of determining the amount of damages to each farm depends largely upon the judgment of the board of appraisers appointed for the drainage district. Consequently there are many variations in the methods followed. The valuation of the various tracts of land taken and of other items of damage are determined by the board, the total amount of each award being subject to court review if appeal is made by the landowner.

It is a common practice to compute as right of way the area occupied by the ditch and waste banks and to allow damages for that acreage at the average value for the whole farm. Some drainage districts have paid only for a strip equal to the top width of the ditch, anticipating that the landowners would plow down and cultivate the waste banks. Some districts have partly leveled the waste banks, and for the area under them have allowed damages equal to two years' rental.

Some drainage districts have built and maintained fences along the right of way, but probably the more common practice has been to include in the damage awards the estimated cost of building the fences if such are deemed necessary. The latter method is not adequate unless the allowance is sufficient to cover repairs and renewals as well as original construction. The cost of bridges to give access to isolated portions of individual farms has been met, in general, like the cost of the fences.

ITEMS OF ACTUAL LOSS

LAND TAKEN FOR RIGHT OF WAY

The most apparent damage suffered by an owner whose farm is crossed by an open ditch is the loss of land occupied by the drain and, ordinarily, by the waste banks. Widths of right of way for ditches of 4-foot and 6-foot bottom widths and 1½ to 1 side slopes and of various depths are stated in Table 6 (p. 11). The wider ditch at 8 feet depth is shown as requiring an 85-foot right of way, which would take 2.57 acres from a square 40-acre field if it crossed parallel to one side *a-b*, (fig. 5), or 3.56 acres if it crossed straight between opposite corners. (*c-d*, fig. 5).

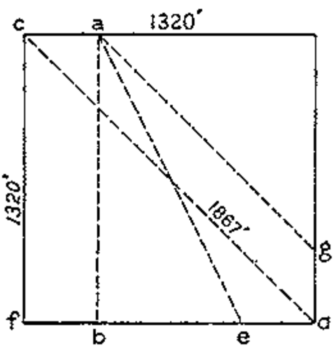


FIGURE 5.—Representative locations of drainage ditches across square 40-acre fields

The waste banks for this ditch cover nearly half the right of way. (Fig. 6, A.) If the material in them would make good soil, it could be spread to have side slopes of 4 to 1 instead of 1 to 1, which would permit farming machinery to be used over them. (Fig. 6, B.) Then the right of way purchased would need be only 46 feet wide, but the damages allowed should cover the extra work of smoothing and preparing the new seed bed and full rental of the land until it yields at least half a normal crop. Leveling the waste banks, when the ditch is constructed, may be expected to add about one-fifth to the price of excavation.

INJURY TO CROPS ADJOINING RIGHT-OF-WAY

Unless the waste banks are leveled, along either side of the right of way through crop land there will be a strip from which the farmer will get but partial returns owing to injury from turning of teams and machinery. If each strip is 20 feet wide and the average yield is half that from land farther from the ditch, the damages from this cause may be estimated as equivalent to purchasing a strip 10 feet wide along each side. If the waste banks were leveled, these turning strips would lie along the edge of the ditch instead of outside the waste banks. Where the ditch is located on a fence line the turning strips along the ditch merely replace those along the fence and would not be considered in computing damages.

LOSS OF PROFITS

A strip of land a few rods wide has greater value as part of the adjoining field than as a separate tract, because of its accessibility for cultivation with that field. Farming a like acreage separately

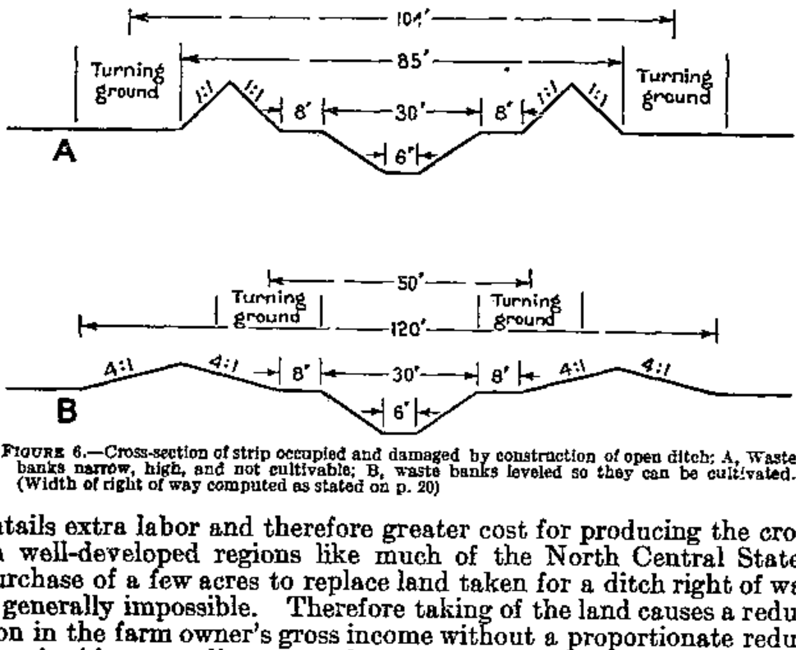


FIGURE 6.—Cross-section of strip occupied and damaged by construction of open ditch: A, Waste banks narrow, high, and not cultivable; B, waste banks leveled so they can be cultivated. (Width of right of way computed as stated on p. 20)

entails extra labor and therefore greater cost for producing the crop. In well-developed regions like much of the North Central States, purchase of a few acres to replace land taken for a ditch right of way is generally impossible. Therefore taking of the land causes a reduction in the farm owner's gross income without a proportionate reduction in his expenditures, and more than a proportionate loss of profits. It would seem only just under such circumstances to compensate the owner for reduction in his profits.

EXTRA LABOR IN WORKING DIVIDED FIELDS

Division of a field of convenient size by a ditch or other obstruction increases the labor of working it. The amount of extra labor required will vary with the kind of crop and the shape of the parts of the field; it may be measured by the loss of time in turning teams and machinery. It is greatest with row crops that are cross-cultivated, and least with crops for which all operations parallel the perimeter of the tract being worked. It increases with the number of rows and crossrows intersected by the ditch.

Division of a rectangular field by a ditch perpendicular to the direction of the long furrows will double the number of turnings in the lengthwise operations and will multiply the turnings in those operations that parallel the perimeter of the field by the ratio of the length of the whole field to its breadth.[4] Division by a ditch parallel to the long furrows will only double the number of turnings in the cross operations. Division diagonally into two equal triangles will double the number of turnings in the lengthwise and cross operations but will make no material change in the labor of the circumferential operations.

In raising a crop of corn on a square 40-acre field divided into two rectangles as by ditch *a-b* in Figure 5, the number of turnings is doubled for probably two harrowings and two cultivations. (All operations in producing the crop are assumed to consist of harrowing, disking, plowing, disking, harrowing, packing, planting, harrowing, cultivating four times, and harvesting.) The extra time required is estimated at 12½ hours for one man and a 2-horse team. Division of the field diagonally as by ditch *c-d* (fig. 5) would double the number of turnings in every operation that must follow the rows or crossrows, which for corn probably would be two harrowings, planting, four cultivations, and harvesting. The extra time for this is estimated as 25 hours for one man and two horses, or double that for the rectangular pieces. Division by a ditch at *a-e* (fig. 5) cutting half the rows and all the crossrows, or at *a-g* cutting three-fourths of the rows and three-fourths of the crossrows, would entail extra labor in cropping equal to three-fourths that resulting from ditch *c-d*, or half more than from ditch *a-b*, about 19 hours for a man and team. For small grains and hay the extra labor would be very small, probably none for the rectangular division, and perhaps four hours for the triangular division.

REDUCTION IN GENERAL FARM VALUE

The presence of an open ditch across a farm generally detracts from the sale value of the farm more than in proportion to the reduction in acreage. Part of this probably is due to fouling of the fields with weeds seeded from the growth in and along the ditch, causing a loss in quality or amount of crop that is none the less real because it is difficult to evaluate. The unsightliness of the ditch and waste banks covered with weeds and brush is also a factor in lowering the value of the farm, because the farm is valued as a home and not merely as income-producing equipment. The effect of this factor probably varies with both physical and economic conditions in the region. In some cases opinion placed the reduction in value due to these causes as high as 10 per cent of the farm value. The unsightliness of the open drain and the losses in crop value resulting from weeds growing along the ditch can be obviated, at least in large measure, by lowering and smoothing the waste banks for cultivation and then occasionally mowing the weeds in and along the channel.

---

[4] Exact computation should deduct a very small number of turnings on account of the area in ditch right of way, which is not cultivated.

COMPUTATION OF TOTAL DAMAGES

A ditch 8 feet deep with 6-foot bottom width and 1½ to 1 side slopes requires a right of way 85 feet wide, according to Table 6. In crossing a square 40-acre field, parallel to one side (*a-b*, fig. 5), the area occupied by ditch and waste banks would be 2.57 acres, which at $100 per acre would have a value of $257. The 20-foot turning strips occupy 1.21 acres, for which damages at 50 per cent of full value would be $60. If the average annual profit from the field is $2 per acre, the loss would be $6.35 per year, which capitalized on a basis of 6.7 per cent interest (the rate used in capitalizing annual expenditures for maintenance of drains) would be equivalent to $95. If this field were worked in a 4-year rotation consisting of corn two years and small grain or hay two years, the average amount of extra labor caused by division of the field would be about six and one-fourth hours for one man and two horses, which at 30 cents per hour for the man and 15 cents per hour for each horse would cost $3.75 per year. Capitalized on a basis of 6.7 per cent interest, this would be equivalent to $56. The total amount of damages computed in this way is then—

Right of way occupied	$257
Turning strips injured	60
Lost profits capitalized	95
Extra labor of farming capitalized	56
Total	468

The cost of leveling the waste banks on this ditch probably would exceed the saving in cost of right of way, and in addition rental would be paid for the land covered by the material.

If the ditch were located along the side of the field, the above-mentioned items for turning strips and extra labor would be avoided, the lost profits would be based on only the 85-foot right of way and be capitalized at $77, and the total computed for the damages would amount to $334.

If the same ditch crossed the field diagonally as at *c-d* (fig. 5), the land occupied by ditch and waste banks would be 3.56 acres and by the turning strips 1.62 acres. Lost profits on the equivalent of 4.37 acres would be $8.74 per year, and the extra labor of working the divided field would average about 14½ hours and would cost about $8.70 per year, at the rates previously stated. The total damages for this case are thus summarized:

Right of way occupied	$356
Turning strips injured	81
Lost profits capitalized	130
Extra labor of farming capitalized	130
Total	697

If the total damages computed above were charged as value of land in the right of way, the prices would be, respectively, $182, $130, and $196 per acre instead of the assumed average selling value of $100 per acre. From these computations are omitted the items of fences, private bridges, and fouling of the field from weed growths along the ditch. It would seem that the drainage district could build and maintain the fences and bridges and mow the weeds more cheaply than pay proper damages for putting the work and expense upon the individual landowners.

The foregoing discussion omits consideration of possible legal obstacles to payment in particular of the item for loss of profits. Nevertheless, failure to receive compensation for such losses doubtless is an important factor in causing opposition to the use of open ditches even when they would be cheaper than tile drains.

CONCLUSIONS

Tile of large diameter have been used for draining land in many instances where open ditches would have provided drainage for less cost. Lack of data for comparing the total cost of drainage by open ditches and by tile undoubtedly has been partly responsible for use of the more costly type of drains.

The annual expenditures for maintenance of tile drains by 106 drainage districts, believed to fairly represent general conditions in the upper Mississippi Valley, averaged about two-thirds of 1 per cent of the cost of the tile and labor of installation. The average annual cost of keeping open ditches in fairly effective condition in the same region is indicated to be about 5 per cent of the cost of excavation and damages.

On the basis of average prices paid for drainage construction during 1922 to 1925 and annual maintenance expenditures capitalized at 6¾ per cent per year, it appears that tile drainage and open ditches may be equal in ultimate cost when purchase of tile and trenching, laying, and back filling will be 70 to 100 per cent greater than the cost of excavation and damages for the open ditch. If the ratio of these installation charges falls within this range, the more economical type of drain is to be determined only by comparing costs according to prices applicable to the case in hand. Use of graphs and formulas given herein will reduce the labor of making such comparisons.

Care in design and construction work will be conducive to low repair costs for tile drains. Inspection should be continued until the last bit of construction is completed.

In appraising damages to be paid for right of way for an open ditch, across cultivated land particularly, cognizance should be taken of other damages than merely the area occupied by the ditch and waste banks. Such damages may result from injury to crops on turning strips along the right of way, from loss of profits through reduction in the size of the farmer's business, and from increased expense of labor for cultivating fields divided by the ditch.

U. S. GOVERNMENT PRINTING OFFICE: 1931

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 5 cents

END