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THE APPLICATION OF THE TECHNICAL-ECONOMICAL INDEXES FOR THE EVALUATION OF THE PRIMARY LAND DRAINAGE NETWORK

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Abstract

A set of technical-economical indexes was introduced in an earlier paper of this volume to evaluate the land drainage canal network of state property in Hungary. The catchments of theses canals form areal units, the so-called land drainage systems. This paper introduces the application of the method for the description and comparison of these areal units with the help of case studies. These case studies cover the fields of a national level grading, the sharing of reconstruction costs, the interest rates of multifunction canals as regional problems. A smaller scale grading is also given to determine an inlet restriction policy in case of a recipient with limited capacity.

Keywords: usefulness of land drainage canal network, benefits of reconstruction, interest rates of multifunction canals, operation under limited inlet capacity

1. Introduction

There is a dense land drainage canal network of state property developed in the lowland area of Hungary. Based on the catchment area of these canals, a set of areal units, the so-called land drainage systems (LDS) are organised. Some of them are split into subsystems as well. The management of such a network always requires carefully made decisions. Several of the primary canals serve also some other purposes, so in their management there may be some other interested parties, as well. The development and layout of the land drainage systems is described in an earlier paper of this volume, where also a method was introduced for the evaluation of these areal units on a technical-economical basis. The main features of the method may be summarised as follows:

- it is uniform over the full country, though it contains the local characteristics of a given region, e.g. in morphology, natural water courses, land use, ownership, etc. as well, to ensure an objective comparison;
- it is based on such global information that reflects the general characteristics of that areal unit with long term reliable parameters that are not the subject of continuous changing causing instabilities;

- it gives an objective way for the evaluation of the operation, maintenance, and development of these lowland catchments;
- in case of planned interventions (e.g. reconstruction or development) it gives a well founded basis for the decision making;
- in case of multiple purpose canals it gives priorities and determines the rate of interests;
- it is understandable and acceptable for all the interested parties within the field of land drainage and out of it, as well.

The method itself is based on a set of indexes to describe several features of the individual units. The indexes define the risk of hazard by the inundation due to insufficient runoff over the catchment and take the level of protection into consideration by the performance and density of land drainage canals.

There are several types of indexes. Those, which are expressed in natural quantities, are called the absolute ones, while those, which are normalised, given in percentages are the relative ones. Absolute indexes may be defined as specific, if they refer to a unit area of catchment or other unit quantity. Otherwise they take the full catchment into consideration, as total indexes. Normalised indexes are usually derived from total indexes. The two most important groups of indexes are

- the *index of usefulness* (total: H [ak/km], specific: h [ak/(ha · km)] and relative: R_H [%]) to show which value is protected by the canals, and
- the *index of demand for development* (total: F [ak/(ha · km)], specific: f [ak/ha · km^2/km)] and relative: R_F [%]) to describe the damages that may arise due to a poor level of service.

The indexes should be determined separately for the winter – spring period and for the growing season, as several parameters are different during the two periods and may be summarised for the full year. Their detailed discussion is given in an earlier paper of this volume.

The data requirement of the method is determined so, that it is based on such well founded information that is available at district water authorities, registered at other governmental bodies, or simple and reliable to estimate. Taking these requirements into consideration, a data base and an evaluation program 'BELREND' (an abbreviated form of 'BELvízRENDezés', i.e. land drainage) was developed. It is assembled with the assistance of the district water authorities, and after a careful control it is returned to them for use and continuous update. Though BELREND is not going to be discussed in details, later several references will be made on it.

The purpose of this paper is to demonstrate the applicability of the method with several case studies. Among these case studies there are surveys on national level, but there are regional problems as well.

2. Grading the Primary Canal Network to Get a General View

2.1. The Problem

As one of the first applications of the method a grading was made over the whole country to get a general view in 1996 (VARGA, 1996). This aimed to reveal the 'present' situation of that time to support the process of decision making in the sharing of the yearly budget.

The grading was prepared based on the specific indexes of usefulness (h) and demand for development (f). The result of it is actually a set of lists containing the catchments and their indexes for the full year in descending order. The lists were prepared on LDS level and also on subsystem level for almost the whole country. Only a few systems of minor importance on the south-west of Hungary were left out. All together an area of 44.600 km^2 with the total canal length of 11.100 km was examined. The average indexes for the whole country were also determined, and classes were set based on them. In this paper only the results of the full land drainage systems will be given in details, but some references will also be made on the subsystem level investigations, as well.

As these investigations cover the whole country, the full data base of BELREND was applied. This data base will not be introduced here in details, only some results will be given.

2.2. The Evaluation of the Results

A shortened form of the LDS level grading for both indexes is given in *Table1*. The first, shaded columns of both sections in the table refer to the grade, the position of the LDS in the list.

Another representation of the results is given in *Figs.1 – 4*. In these figures the vertical axis is the given index, while the horizontal axis is the cumulated catchment area or canal length of the land drainage systems having the given or higher index. The average values are also presented there. The figures show what part of the whole country formulated in catchment area or canal length belongs to a given or larger index value. In some sense these figures are similar to the duration curves of statistics.

Based on the table and the figures the following can be established:
index of usefulness:

- the range of the index is 0 – 30 ak/(ha · km) on LDS level, and 0 – 110 ak/(ha · km) on subsystem level;

  The examinations on subsystem level always show higher extreme values, while on LDS level these extreme values are more eliminated.

- the average value is independent from the level of examinations, it is 9.114 ak/(ha · km) for the whole country;

Table 1. Grading based on specific indexes

specific index of usefulness						specific index of demand for development					
Gr.	LDS	A[km^2]	L[km]	h [ak/(ha · km)]	class	Gr.	LDs	A[km^2]	L[km]	h f[ak/(ha · km)]	class
1	1	298.5	150.231	28.877	+	1	39	533.8	100.000	637.670	++
2	71	87.0	61.700	27.443	+	2	48	1910.0	126.837	424.347	++
3	82	57.2	26.300	23.676	+	3	11	430.6	47.100	132.214	++
4	72	623.0	215.200	23.083	+	4	55	166.0	74.100	88.775	+
5	76	84.4	39.800	21.686	+	5	40	425.6	45.400	58.859	+
6	41	119.0	76.800	20.646	+	6	62	361.2	108.499	46.007	+
7	14	148.6	48.298	19.812	+	7	63	398.4	135.601	46.007	+
8	5	44.1	3.832	19.288	+	8	10	295.0	20.500	43.630	+
9	43	416.0	172.169	18.736	+	9	18	1050.0	140.717	28.535	–
10	42	540.0	294.890	18.414	+	10	37	937.4	224.000	27.074	–
11	3	1533.3	593.333	17.996	+	11	34	1411.4	254.900	18.072	–
..						12	82	57.2	26.300	17.628	–
22	62	361.2	108.499	14.659	+	13	53	135.0	22.700	17.134	–
..						14	69	208.0	79.900	15.491	–
31	63	398.4	135.601	12.294	+	..					
..						27	51	356.2	47.410	6.500	–
34	55	166.0	74.100	11.005	+	..					
..						36	76	84.4	39.800	2.715	–
37	54	656.6	126.700	9.510	+	..					
38	77	2131.4	411.000	9.189	+/–	41	41	119.0	76.800	1.755	–
39	58	560.9	91.000	9.019	+/–	..					
40	25	553.0	182.579	8.971	+/–	46	1	298.5	150.231	0.456	–
41	22	607.2	166.695	8.824	+/–	..					
42	61	953.3	290.003	8.698	+/–	63	24	1062.5	387.424	0.007	–
43	67	483.7	160.100	8.606	+/–	64	22	607.2	166.695	0.000	–
44	75	1008.8	172.200	8.577	+/–	65	25	553.0	182.579	0.000	–
45	35	251.7	52.700	8.438	–	66	26	44.3	20.460	0.000	–
..						67	30	833.8	138.989	0.000	–
63	39	533.8	100.000	4.570	–	68	31	476.8	60.802	0.000	–
64	53	135.0	22.700	4.429	–	69	35	251.7	52.700	0.000	–
65	11	430.6	47.100	3.748	–	70	36	156.9	61.200	0.000	–
..						71	38	87.9	35.700	0.000	–
69	40	425.6	45.400	3.227	–	72	70	533.0	237.300	0.000	–
70	48	1910.0	126.837	2.947	–	73	71	87.0	61.700	0.000	–
..						74	72	623.0	215.200	0.000	–
73	10	295.0	20.500	2.460	–	75	78	40.9	5.900	0.000	–
..						76	80	2273.3	507.500	0.000	–
77	81	232.2	20.400	0.048	–	77	83	186.6	50.700	0.000	–
78	51	356.2	47.410	0.000	–	78	84	3209.0	550.839	0.000	–

- *Figs.* 1 and 2 show that both curves are rather flat, the average cannot be considered as a sharp limit, therefore an interval of $8.5 - 9.5$ ak/(ha · km) is applied;
- three classes were defined, as *above average* (signed with + in *Table* 1), *around average* (sign: $+/-$) and *below average* (sign: –);
- the total catchment area in the class *above average* is 18000 km^2, 40% of the whole area examined, *around average* is 6000 km^2 (14%) and, less than a half, 20600 km^2 (46%) is *below the average*;
- the total length of canals *above average* is 5700 km (51%), *around average* 1400 km (13%) and *below average* 4000 km (36%);
- the differences between the percentages of area and length show that high specific index of usefulness can be gained on regions with high canal density;
- only one full LDS has zero usefulness (LDS 51, Rekettyés), with the catchment of 356 km^2 and the canal length of 47 km;
- the more refined results of subsystem level investigations show that a catchment of 661 km^2 (1.5%) with the canal length of 78 km (0.7%) has no usefulness.

index of demand for development:

- the range of the index is $0 - 640$ ak/ha · km^2/km on LDS level, and $0 - 2500$ ak/ha · km^2/km on subsystem level;
- the average value is 33.035 ak/ha · km^2/km for the whole country;
- *Figs.* 3 and 4 show that this average is around a sharp change in the character of the curve, so it can be taken into consideration as a single value;
- in this case also three classes were defined, as *extreme high* (signed: $++$) with the limit of 100 ak/ha · km^2/km, *above average* (sign: $+$) and *below average* (sign: $-$);
- the total catchment area in the class *extreme high* is 3000 km^2 (7%), *above average* 2050 km^2 (5%) and *below average* 39550 km^2 (88%);
- the total length of canals the class *extreme high* is 300 km (2.7%), *above average* 400 km (3.6%) and *below average* 10400 km (93.7%);
- the differences in percentage show that in case of high specific index of demand for development the canal density is usually low;
- several full LDS have zero index, with the catchment of 9964 km^2 (22%) and the canal length of 2348 km (21%);
- the more refined results of subsystem level investigations show that a catchment of 10064 km^2 (23%) with the canal length of 2675 km (24%) has zero index of demand for development.

It may also be interesting to compare the two indexes in case of some LDS with extreme values:

- LDS 1, 71 and 72 with very high index of usefulness have zero or almost zero index of demand for development;
- LDS 11 and 48 with high demand for development have very low usefulness;

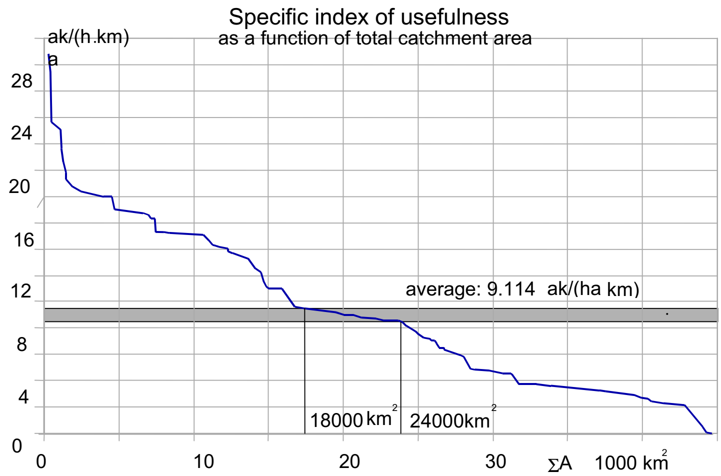

Fig. 1. Specific index of usefulness as a function of total catchment area

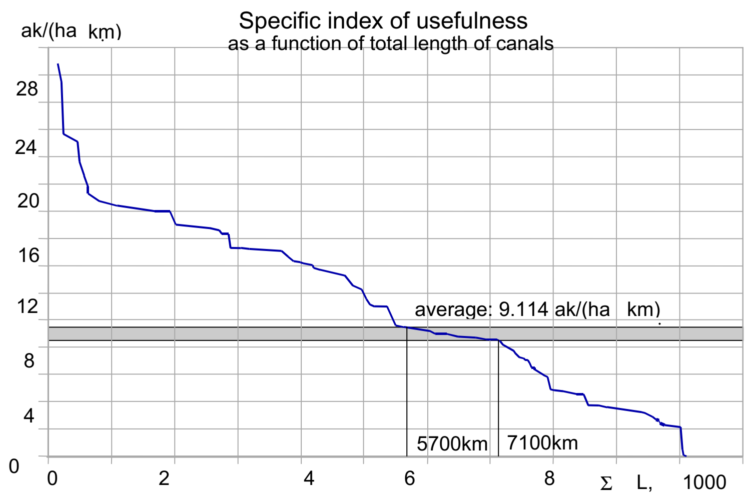

Fig. 2. Specific index of usefulness as a function of total length of canals

- in several other cases (e.g. LDS 22, 51, 82, etc.) the above considerations cannot be followed clearly, some other local effects may dominate, e.g. a relatively dense network serves a poor quality of land, etc.

Generally, for the two indexes it can be established, that flat, smooth curves for the index of usefulness with low extreme values show a uniform protection potential of the land drainage network, while sharp extreme values in the index of

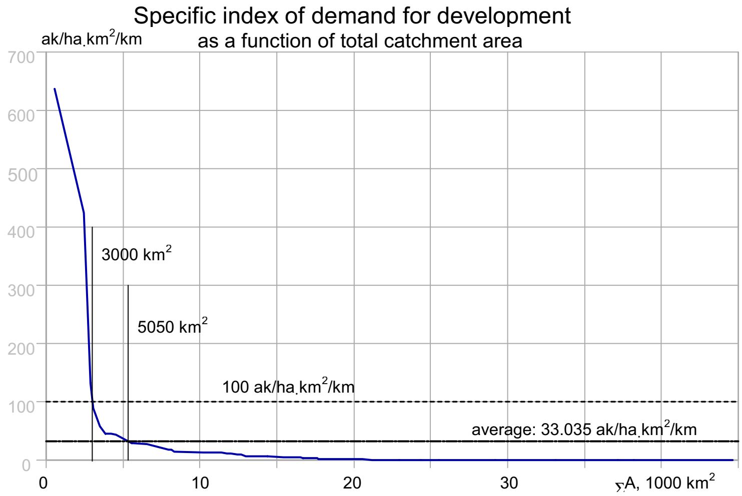

Fig. 3. Specific index of demand for development as a function of total catchment area

demand for development show some underdeveloped regions. It is advantageous to make every effort to get a uniform protection potential over the whole country and to reduce the magnitude of underdeveloped regions in order to ensure safe conditions for the agriculture.

Finally it is remarkable, that after these investigations study plans were made for the development of the primary canal network in several regions. Among these regions the full LDS 51 with the lowest usefulness and LDS 48 subsystem 2, with one of the highest demands for development also appeared. The decision which region to develop was made not only on the basis of the above grading, but beside other considerations these grades were also of decisive importance.

3. The Grading of the Reconstruction of the Primary Canal Network

3.1. The Problem

In 1997 a survey was made over the whole country to determine what reconstruction costs may arise to restore the nominal parameters of the primary canal network. The costs were determined based on the local norms of the district water authorities.

> In Hungary there are twelve district water authorities (DWA), which does not follow the administrative borders of the nineteen counties, but rather the catchments of water courses.

The following costs were determined on subsystem level:

- silt removal in the canals,
- reparation and renovation of
  - canal lining,
  - pumping stations,
  - reservoirs,
  - structures,
  - canal keepers' workshops and other accessories.

All together 172 subsystems were included in the survey with the catchment area of almost 41000 km^2. The full estimated cost is almost 13700 million Ft.

Beside the cost estimations, a schedule was also made for the coming five years, i.e. 1998 – 2002. The area influenced by the reconstruction and its estimated costs for each year are given in *Table 2*. Based on the given percentages it can be seen, that both area and costs are unevenly distributed in the period. In the first part larger area with higher costs is planned, while later smaller area with smaller costs.

Table 2. Yearly parameters of reconstruction

year	No. of subs.	A [km^2]	A [%]	h [ak/(ha · km)]	E [1000 Ft]	E [%]	h_E [ak/(km · 1000Ft)]
1998	51	8836.7	21.6	10.298	3,604,325	26.3	2.52
1999	30	10722.8	26.2	7.150	3,290,352	24.0	2.33
2000	36	10786.2	26.3	9.237	2,547,631	18.6	3.91
2001	28	5342.1	13.0	7.049	2,210,268	16.1	1.70
2002	27	5295.6	12.9	8.061	2,037,655	14.9	2.09
total	172	40983.4	100.0	8.482	13,690,231	100.0	2.54

As the full costs were not provided by then, based on the above information the following questions were to be answered:

- which is the most effective way to share the limited costs,
- which reconstruction is worth supporting and which one is not,
- whether the time schedule based on other considerations is acceptable or not,
- as the financial support has to be distributed among the DWA-s, how to give an objective and clear explanation why the reconstruction on their territory is supported or why not.

3.2. The Index of Reconstruction Usefulness

The most suitable way to answer the above questions was to compare the nominal and 'present' parameters of the primary land drainage network, e.g. with the help of nominal and present indexes of usefulness. But there was no direct information about the 'present' conditions, only the estimated costs, which indirectly contained this information. The time for the examinations was too short, so it was impossible to collect any new information. Therefore the following considerations were made:

- the nominal parameters and all the indexes based on them were provided in the data base of BELREND, so it could be used as it was;
- the intervention was reconstruction and no development was planned, so the index of usefulness (h or H) had to be applied to characterise the conditions to be achieved;
- the present situation by then could be described by the demand of reconstruction formulated by its estimated costs.

Based on them, a new specific index, the *index of reconstruction usefulness* was defined as follows:

$$h_E\ (x = 0)\ [\text{ak/(km} \cdot \text{Ft)}] = \frac{H(x = 0)}{E(x = 0)},$$

where:

$$E\ [\text{Ft}]\ :\ \text{estimated costs of reconstruction.}$$

Index h_E shows what value formulated in usefulness will be restored due to a unit sum of reconstruction cost. This index characterises the efficiency of the investment expended on the reconstruction.

3.3. *The Evaluation of the Results*

Table 2 with the catchments and costs also contains the average specific indexes of usefulness and the new index h_E for each year and for the full period as well. Based on the table the following can be established:

- The average index $h = 8.482$ ak/(ha · km) is smaller than that of point 2.2, which is $h = 9.114$ ak/(ha · km). It reflects, that some of those subsystems which had high usefulness in the former point are in good conditions, they need no or negligible reconstruction, so they are left out of this survey.
- The higher usefulness does not always mean a high effectiveness of reconstruction.
- In the first part of the period an average or higher effectiveness may be expected, while in the second part lower.

This time schedule seems to be advantageous, as the more effective subsystems are planned to be reconstructed earlier, while those with lower effectiveness are postponed. In case of them it may be advisable to revise if they are worth to reconstruct or not. Maybe another intervention, the development to increase their performance could yield higher benefits. Therefore the postponement gives sufficient time to reconsider the tasks.

Table 3. Grading of the reconstruction

Gr.	LDS	subs.	DWA	year	A [km^2]	h [ak/(ha · km)]	E [1000 Ft]	h_E [ak/(km · 1000 Ft)]
1	43	4	7	2002/1	10.0	22.158	200	110.79
2	65	1	10	2002/2	93.7	11.266	2,000	52.78
3	62	2	10	2002/3	19.0	17.514	850	39.15
4	23	5	8	1999/1	80.3	19.734	4,100	38.65
..								
7	66	2	10	1999/2	75.0	10.774	3,200	25.25
..								
9	29	4	10	2001/1	28.5	30.474	3,800	22.86
10	46	1	7	2000/1	1889.0	16.782	172,400	18.39
11	23	1	8	1998/1	42.8	6.097	1,700	15.35
12	45	3	7	1998/2	260.0	16.668	28,600	15.15
..								
14	63	3	10	2001/2	18.0	14.726	2,000	13.25
15	80	5	11	2000/2	1213.4	12.972	119,734	13.15
..								
17	63	1	10	1998/3	247.6	14.379	28,450	12.51
18	71	1	12	2000/3	87.0	27.443	22,700	10.52
..								
23	21	1	7	1999/3	150.0	19.254	30,450	9.48
..								
28	44	6	7	2001/3	7.0	57.494	4,900	8.21
..								
150	12	1	4	1999/28	415.0	2.655	153,000	0.72
151	4	6	1	2002/25	18.2	8.080	21,440	0.69
152	79	5	11	1999/29	127.0	1.558	29,291	0.68
..								
157	56	3	9	2002/26	134.9	1.040	25,224	0.56
158	14	4	2	2002/27	32.0	1.832	10,800	0.54
..								
160	23	4	8	1998/47	52.5	12.154	132,400	0.48
161	33	3	11	2000/34	305.6	1.306	82,869	0.48
..								
163	83	3	11	2001/26	8.7	17.459	56,313	0.27
..								
165	16	3	2	1999/30	22.0	7.175	99,000	0.16
166	24	9	8	1998/49	11.0	3.762	27,300	0.15
167	74	3	12	2001/27	155.9	0.118	13,200	0.14
168	14	3	2	2000/35	3.0	3.449	9,000	0.11
169	27	3	10	1998/50	56.6	0.000	9,000	0.00
170	81	1	11	1998/51	214.5	0.000	5,746	0.00
171	51	1	10	2000/36	356.2	0.000	59,250	0.00
172	66	1	10	2001/28	34.0	0.000	2,200	0.00

A more detailed evaluation can be made on the grading, which was prepared for the full reconstruction without taking the time schedule into consideration, and also based on the schedule for each of the five years independently. *Table 3* contains a shortened form of the full grading. It shows only the first and last three subsystems of each year in the descending order of h_E for the full period. The column 'year' contains not only the scheduled time of the reconstruction, but after the slash the grade of the subsystem within its year is also given. In the column 'DWA' the numbers of those district water authorities (1..12) appear, whose territory that certain subsystem is. Based on *Table 3*, it can be seen, that

- Usually subsystems with small size but high usefulness have a high effectiveness of reconstruction, as relatively small costs restore the protection of a high value.
- Four subsystems with the total catchment of more than 660 km^2 (1.2% of the total) have zero usefulness, so the reconstruction costs of 76.2 million Ft (0.6% of the total) have no benefits. In case of these subsystems, and also of those with very low index h_E rather development than reconstruction is needed.
- Leaving those DWA-s out of consideration, whose territory is mainly the hilly south-western part of the country (No. 4, 5 and 6), the more efficient reconstruction may be expected on the eastern, more agricultural part of the country (No. 7 – 12), while inefficient reconstruction may appear almost all over.

Though this type of grading was mainly in accordance with the long term experiences, at some points it was inconsistent with the traditions. Finally the decision was made with the help of the above grading, and the later experiences showed its efficiency. Nevertheless, once again it has to be emphasised, that it cannot be the only factor to be considered. In such a decision making process regional and local policy, the requirements of agriculture and its market, employment, nature protection, etc. play also an important role.

4. Inlet Restrictions in Case of Recipient with Limited Capacity

4.1. The Problem

All the indexes defined earlier take the performance of the canal network into consideration, and assume that the recipients have a sufficient capacity to divert that certain amount of water. But several recipients, mainly smaller rivers, river branches or regional canals may be overloaded in case of extreme situation. A typical example is if an early spring flood on the river coincides with the high runoff from the catchment due to snow melt and/or high precipitation. To avoid inundation along the recipient, there may be limitations in the inlet of excess water. Such problems arose also in the spring of 1999 at the eastern part of the country.

To protect the recipient and to avoid higher damages along it, limitations have to be introduced on the catchment to reduce the amount of water to be let in. Usually such a recipient serves several LDS-s or subsystems, so it is always a problem if all of them should be limited, or not, and if only some of them then which one. Of course such a limited inlet will cause inundation and damages on the catchment, so it is of high importance to find an optimum. Such inundation that is not caused by the insufficient operation of the land drainage network, but by the limited capacity of the recipient is called the indirect flood inundation.

Similar problems may arise south to Budapest, along the Ráckeve (Soroksár) Danube branch (R/S/D). It used to be a left side natural branch of the river Danube with the length of 57 km. At its upper end the Danube had a very wide and shallow bed sensitive for ice jam forming before its regulation. Such an ice jam caused the catastrophic flood of 1838 which destroyed large parts of the capital. In order to avoid such ice jam forming, after the flood the main stream was directed to the western, today main branch with higher depth and velocity in it, and R/S/D was closed by river barrages at both ends to form an almost still standing water body. As the lower river barrage was seriously damaged in the icy flood of 1956 it was broken down. Only its navigation lock was reconstructed to operate as an outlet gate as well, without shortening its original purpose. Though it is a temporary solution, the reconstruction of the full barrage is only planned.

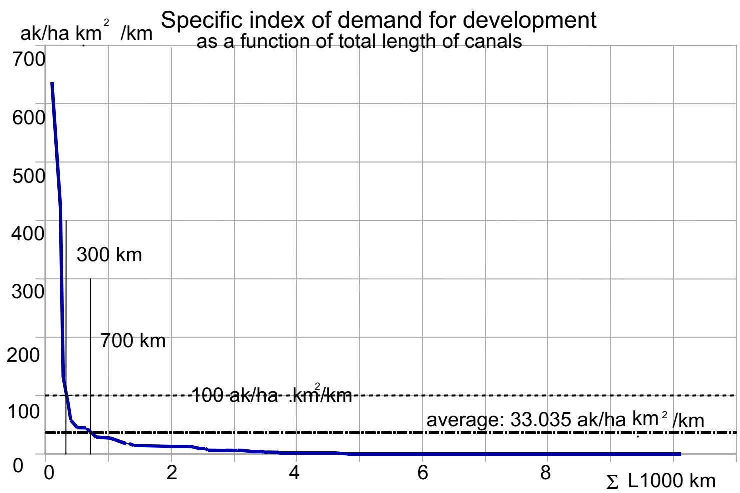

Fig. 4. Specific index of demand for development as a function of total length of canals

R/S/D is the recipient of six subsystems, belonging to three LDS-s, with the total catchment of 1514 km^2 and the total capacity of 32.05 m^3/s. In case of low or medium water level in the Danube the lower river barrage has a sufficient head to let this amount of water into the Danube. But if there is flood on the Danube this head may sharply decrease, and it may even be negative.Though there is a

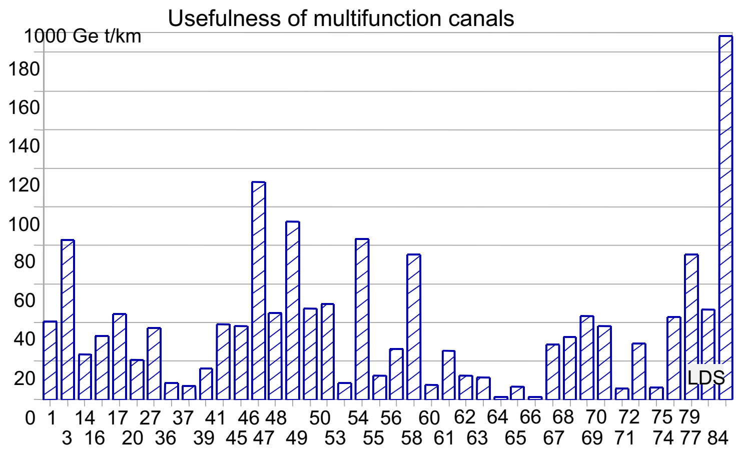

Fig. 5. Usefulness of multifunction canals

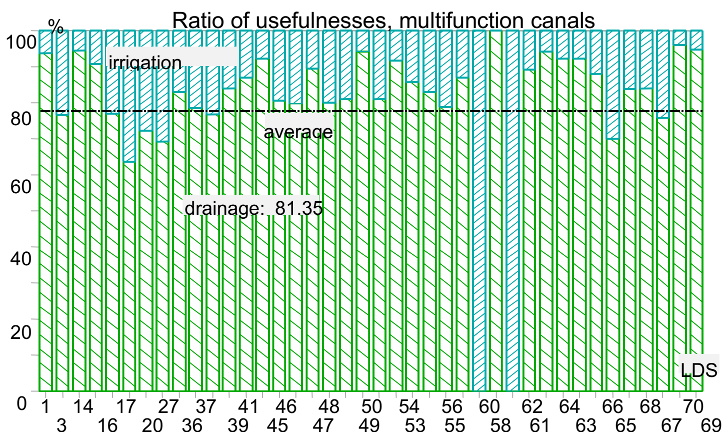

Fig. 6. Ratio of usefulnesses, multifunction canals

limited pumping capacity as well, the full amount of water cannot be let out. As along the R/S/D there are several inhabited and recreational areas, an inundation along the branch itself could cause much higher damages, than an inundation on the catchment.

In this point a grading is presented to decide which of the six subsystems should suffer inlet restrictions to avoid higher damages along R/S/D (VARGA, CSOMA, 1998). As this example covers only a few subsystems, a detailed description of data and results is given. For this once again the data base of BELREND was used. *Table 4* contains the most important data of the six subsystems.

Table 4. Basic data of the subsystems along R/S/D

LDS	subs.	A [km^2]	a [ak/ha]	α_1 [−]	α_2 [−]	Q [m^3/s]	V [m^3]	L [km]	τ [day]
14	1	64.9	18.0	0.21	0.08	1.95	0	30.486	1.3
14	3	3.0	19.9	0.14	0.05	0.35	0	0.100	0.1
14	4	32.0	20.9	0.13	0.04	0.70	0	0.642	0.1
15	1	391.3	13.2	0.15	0.05	12.05	90000	68.500	0.6
16	1	708.7	9.8	0.11	0.04	13.00	0	62.542	2.3
16	2	314.1	14.8	0.21	0.09	4.00	0	82.043	2.1
sum/ave		1514.0	12.3			32.05	90000	244.313	

4.2. Applied Indexes

The calculated parameters and applied indexes are given in *Table*5. The inundation time and the specific index of usefulness are given separately for the winter – spring period and for the growing season. Index h for the full year is also given as the sum of the two periods. It can be seen that except of 14/1 all the subsystems have a lower specific index of usefulness than the average, $h = 9.114$ ak/(ha · km) of point 2.2. Beside the specific, total and interest indexes of usefulness, a new index appears, the *specific index of discharge usefulness*. It is defined as follows:

$$h_Q\ (x = 0)\ [\text{ak}/(\text{m}^3/\text{s} \cdot \text{km})] = \frac{H(x = 0)}{Q(x = 0)}.$$

This index shows what value formulated in usefulness a unit discharge capacity protects. As the limitations appear in a reduced discharge inlet into the R/S/D from the land drainage canals, such an index may also be characteristic.

Table 5. Calculated parameters of the subsystems along R/S/D

LDS	subs.	t_{kw} [day]	t_{kg} [day]	h_w [ak/(ha · km)]	h_g [ak/(ha · km)]	h [ak/(ha · km)]	H [100 ak/km]	R_H [%]	h_Q [100ak/(m^3/s · km)]
14	1	0.694	0.056	11.649	12.189	23.838	1547.1	18.8	793.38
14	3	0.003	0.000	1.724	1.725	3.449	10.3	0.1	29.56
14	4	1.081	0.320	0.911	0.921	1.832	58.6	0.7	83.75
15	1	0.455	0.032	3.537	3.647	7.184	2811.1	34.2	233.29
16	1	0.561	0.010	1.040	1.088	2.128	1508.1	18.3	116.01
16	2	2.341	0.320	3.405	3.892	7.297	2292.0	27.9	573.00

4.3. The Evaluation of the Results

The grading was prepared in three different ways, based on the specific and interest indexes of usefulness, and also on h_Q. The results are given in *Tables* 6–8. These

Table 6. Grading based on the specific index of usefulness

Gr.	LDS	subs.	h [ak/(ha · km)]	Q [m^3/s]	$\sum Q$ [m^3/s]
1	14	1	23.838	1.95	1.95
2	16	2	7.297	4.00	5.95
3	15	1	7.184	12.05	18.00
4	14	3	3.449	0.35	18.35
5	16	1	2.128	13.00	31.35
6	14	4	1.832	0.70	32.05

tables also contain the discharge capacity of each subsystem, and the cumulated discharge as well. The three different ways of grading show, that

- the first three and last three subsystems are the same in all the three lists, only their position is different;
- subsystem 16/2 always takes the second position;
- 14/1 is the first in case of the specific indexes of h and h_Q;
- 15/1 – opposite to 14/1 – is the first in case of the interest index due to its larger size, otherwise it is the third;
- the two subsystems of 14/3 and 14/4 with the smallest performance are usually the last because of their low service level;
- 16/1, the largest subsystem with the lowest productivity is third or fourth.

Table 7. Grading based on the interest index of usefulness

Gr.	LDS	subs.	R_H [%]	Q [m^3/s]	$\sum Q$ [m^3/s]
1	15	1	34.2	12.05	12.05
2	16	2	27.9	4.00	16.05
3	14	1	18.8	1.95	18.00
4	16	1	18.3	13.00	31.00
5	14	4	0.7	0.70	31.70
6	14	3	0.1	0.35	32.05

The maximum permissible discharge to be let into the R/S/D depends always on the hydrological situation and the operation of the river barrage at the outlet. Though the modified navigation lock has a maximum capacity of 50 m^3/s, in case of high water level in the Danube its capacity may be much smaller. And it is also possible, that the Danube flood is higher than the water level in the branch. In this case the lock is closed, there is no way for gravitational outlet, only pumping is possible with a relatively small capacity. Therefore it is not possible to prescribe in advance a full strategy to determine which catchment a restriction should suffer, it is always a decision suited to that certain situation. As an example, if the total inlet to the R/S/D is restricted to 20 m^3/s, and each subsystem should operate with full capacity, then based on *Tables* 5–8, the following strategy may be applied:

- subsystems 14/1, 16/2 and 15/1 with the total discharge of 18 m^3/s are not restricted,
- subsystem 14/4 has to be closed.
- further there are two possibilities, as follows:
  - either subsystem 14/3 is also not restricted, and the capacity of 16/1 is sharply reduced,
  - or subsystem 14/3 is closed with a less reduction in 16/1.

This strategy may be once again only one point in the decision making, as several other considerations may also be of basic importance.

5. Interest Rates of Multifunction Canals

5.1. The Problem

Several of the primary land drainage canals serve multiple functions. Multifunction canals may deliver irrigation water in the dry season, fill or empty fishing ponds, supply rice plants or serve other, non-agricultural purposes. The aim of this point is to show how the above indexes may be applied for determining the interest rates of the different parties using the canal system.

A detailed survey was made in 1995-98 (VARGA, SZALAY, CSOMA, 1998) among others to summarise the most important characteristics of those land drainage canals, which as a secondary function also supply water for the agriculture. The survey covered 40 LDS-s and almost 250 canals. These canals have all together the catchment of 23000 km^2, and the total length of more than 3000 km. Though the main item in the water supply is the irrigation, the water demand of rice plants and fishing ponds was also taken into consideration. Based on the survey a detailed data base was also assembled for these multifunction canals. This data base has three parts, one for land drainage, the second for agricultural water supply and the third for regional agricultural parameters.

The land drainage part contains all the data that also appeared in BELREND, but now not for the subsystems, but for each multifunction canal.

The second part also aimed to describe the individual canals, but in this part from the point of view of agricultural water supply, with the following parameters:

- water distribution capacity of the canal;
- licensed water intakes;
- size of irrigated and irrigable land over the service area of the canal;
- extension of rice plants and their water demand over the service area, if there is any;
- fishing ponds and their water demand, if there is any;

- guaranteed intakes and outlets from/to other canals;
- the source of water diverted into the canal, etc.

The third part of the data base is organised on the LDS level. Based on long term agricultural recordings the following parameters were taken into consideration:

- areal distribution of crops of eight main groups, as wheat, maize, sugar-beet, lucerne, potato, sunflower, pea and grass;

  These groups contain not only the sowing area of the individual plants given above, but that of all the similar plants belonging to the same group

- the corn equivalence of the above groups;

  This parameter helps to transform the crop distribution into a uniform one of a ‘virtual crop’. This virtual crop is the wheat. All the further parameters were also transformed to that of ‘virtual wheat’ with the help of corn equivalence . That is how numerous calculations with the eight crop groups could be avoided.

- crop irrigation requirements for the driest decade in the growing season for the different plants and an areal average based on corn equivalence;
- specific yield in corn equivalent tonnage over hectares (Ge t/ha) without and with irrigation;

  Corn equivalent tonnage describes the yield of a unit area in tons taking into consideration the corn equivalence defined before.

5.2. The Modified Index of Usefulness for Multifunction Canals

Based on the data base of Point 5.1 such indexes of usefulness had to be defined for land drainage and agricultural water supply separately that are comparable. The specific productivity a[ak/ha] applied earlier was in this case not suitable, as it represents the value of fertile land. This value is independent of how that land is cultivated, it is the same with or without irrigation. So instead of specific productivity the specific yield was used. This parameter is less reliable than specific productivity, as it may be a subject of long term variations, but this is how the benefits of both land drainage and irrigation may be compared.

In case of land drainage the specific index of usefulness is then

$$h_L\ (x = 0)\ [\text{Ge t}/(\text{ha} \cdot \text{km}] = S\ (x = 0) \cdot ge_0,$$

where:

$S(x = 0)$ [1/km]	: the index of service level;
ge_0 [Ge t/ha]	: specific yield without irrigation.

Table 8. Grading based on the specific index of discharge usefulness

Gr.	LDS	subs.	h_Q [100 ak/(m^3/s · km)]	Q [m^3/s]	$\sum Q$ [m^3/s]
1	14	1	793.4	1.95	1.95
2	16	2	573.0	4.00	5.95
3	15	1	233.3	12.05	18.00
4	16	1	116.0	13.00	31.00
5	14	4	83.7	0.70	31.70
6	14	3	29.6	0.35	32.05

This specific index of usefulness is actually the specific yield that the given canal protects. The total index of usefulness is then the full yield over the catchment of the canal:

$$H_L\ (x = 0)\ [\text{Ge t/km}] = h_L\ (x = 0) \cdot A\ (x = 0)\,.$$

As irrigation can be expected only in the growing season, these indexes of usefulness were defined for this period. The values of h_L and H_L were determined independently for each multifunction canal and the total index was summarised over the corresponding LDS-s.

In case of agricultural water supply the determination of usefulness requires some more considerations. Crop irrigation requirement and the capacity of the given canal make possible to determine the irrigated area which may be fully supplied with twelve hours/day continuous irrigation. The irrigated area is:

$$A_I\ [\text{km}^2] = 423\frac{Q\ (x = 0)\ [\text{m}^3/\text{s}]}{v\ [\text{mm}/10\ \text{days}]},$$

where:

v [mm/10 days] : average crop irrigation requirements for the driest decade in the growing season.

The canal density of this irrigated area is then:

$$c_I\ (x = 0)\ [1/\text{km}] = \frac{L}{A_I(x = 0)}.$$

Specific usefulness of irrigation is the extra yield provided by the canal described by its density:

$$h_I\ (x = 0)\ [\text{Ge t(ha} \cdot \text{km}] = c_I\ (x = 0)\ (ge_I - ge_0),$$

where:

ge_I [Ge t/ha] : specific yield with irrigation.

In this case the section $x = 0$ is the water inlet section of the canal at its water base. The total index of usefulness is then the total yield over the irrigated area:

$$H_I\ (x = 0)\ [\text{Ge t/km}] = h_I\ (x = 0) \cdot A_I\ (x = 0).$$

Same as the indexes h_L and H_L, the values of h_I and H_I were also determined independently for each canal and the total index was summarised over the corresponding LDS-s.

The compound index of usefulness in case of an LDS is:

$$H_{LDS} = \sum_{i=1}^{n} H_L\ (x = 0) + \sum_{i=1}^{n} H_I\ (x = 0),$$

where:

n : the number of multifunction canals in the given LDS.

H_{LDS} is the sum of the yield protected and the extra yield provided by all the multipurpose canals of a certain LDS.

Based on the total indexes, the interest indexes of land drainage and irrigation in an LDS are as follows:

land drainage:

$$R_L[\%] = \frac{\sum_{i=1}^{n} H_L\ (x = 0)}{H_{\text{LDS}}} \cdot 100,$$

irrigation:

$$R_I[\%] = \frac{\sum_{i=1}^{n} H_I\ (x = 0)}{H_{\text{LDS}}} \cdot 100.$$

The interest indexes show how the benefits of operating and maintaining the multipurpose canals are shared among drainage and irrigation.

5.3. The Evaluation of the Results

Based on the above considerations, all the different indexes of usefulness were determined for the individual canals, and also for those LDS-s in which there is a multifunction canal. Without giving the details of the canals, here only the usefulness on LDS level will be discussed. The compound indexes of usefulness are given in *Fig. 5*, while the interest indexes of land drainage and irrigation are given in *Fig. 6*. Only those LDS-s appear in both figures, in which multifunction canals are in operation. The figures show that

- Most of the multifunction canals appear on the eastern, flat part of the country, on the catchment of the River Tisza (LDS No. 27 – 79), where also the precipitation is lower, than the average.
- The high values of compound usefulness usually belong to LDS-s with larger size, while the smaller values do not always appear in smaller LDS-s, but rather on those with rare canal network and/or low yield.
- The average interest index of land drainage is 81.35%, while that of irrigation is 18.65%.
- There are two LDS-s, (No. 64 and 66) in which the usefulness in land drainage is zero, which reflects that these canals have no benefits in drainage.
- There is only one LDS (No. 65) in which the usefulness in irrigation is zero. In this LDS of smaller size there is only one multipurpose canal with a low water distribution capacity. Along this canal there is no irrigation, it diverts water to another LDS, so its benefits are realised outside of LDS 65.
- If these three special LDS-s were left out of the average, the interest index of land drainage were 81.44% and that of irrigation were 18.56%. The small difference in the average values shows, that these three LDS-s are of minor importance compared to the whole country.

Though it was always well known that in case of multipurpose canals the major purpose is land drainage and agricultural water supply is always secondary, this was the first time that their importance is expressed in numerical form. These interest indexes give a well founded basis to the authorities to share the operational and maintenance cost of multifunction canals.

This example also showed that within the basic guidelines of the method, indexes may be flexibly adjusted to the requirements of the problem concerned.

6. Summary and Conclusions

The present paper introduced the application of a method and evaluation of the primary land drainage network.

The method is based on regional meteorological, agricultural and land use information and also on the most important parameters of the canal network. Though it is based on the so called land drainage systems, smaller areal units can also be used. With the help of this information a set of indexes can be determined to describe different characteristics of the network.

Four case studies were given in details. They are as follows:

- a general survey over the full country to get an overview about the given situation;
- the grading of all the land drainage systems from the point of reconstruction;
- a regional survey in case of inlet restrictions with a recipient of limited capacity,
- the interest rates of multifunction canals.

The case studies show that the method has a wide range applicability. Each of them demonstrates how the requirements set earlier are fulfilled.

- They use the same reliable information all over the country, so the indexes are comparable and objective;
- Several of the results are in accordance with long term experiences, though in some cases they help to discover some contrary;
- The grading is flexible, like in the first case study, where in case of usefulness the average was determined as an interval, while in case of demand for development it was given as a single value;
- Though the basic indexes are already defined and widely used, it is flexible to determine such new indexes that describe the given problem in the best way (Points 3.2, 4.2 and 5.2);
- Helps the decision making in a clear way, like in case of the second case study to determine which reconstruction to support;
- Gives the interest rates of the different users of the canal network in a simple and clear way, like in the fourth case study;
- May be applied on national, regional and local level, as well.

Though it is never the only aspect to be considered, the wide range application of the method proved that it is a useful tool for both the National Water Authority in national decisions and the district water authorities in regional and local decisions.

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