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TECHNICAL-ECONOMICAL BACKGROUNDS FOR THE EVALUATION OF THE PRIMARY LAND DRAINAGE NETWORK

Rózsa CSOMA and István VARGA

Department of Hydraulic and Water Resources Engineering
Technical University of Budapest
H-1521 Budapest, Hungary
Fax: + 36 1 463-4111, Phone: + 36 1 463-1495

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Abstract

There is a dense land drainage canal network of state property 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 are organised. The management of such a network always requires carefully made decisions. This paper introduces a method for the description and comparison of these areal units on a technical-economical basis. The method is based on well founded data giving general information about the area concerned, and provides a clear set of indexes for the evaluation. Though they are never the only parameters to be considered, the method is suitable to support a wide range of decisions on national, regional and local level.

Keywords: management of land drainage canal network, technical-economical indexes.

1. Introduction

Almost half of the 93 000 km^2 area of Hungary is a lowland region, and a reasonable part of it has no sufficient or limited morphological conditions for natural runoff. That is why land drainage is of exceptional importance.

During the ages a relatively dense drainage canal network with the corresponding structures has developed over this area. A part of the canals has a natural origin, e.g. creeks or dead branches of rivers, others are pure artificial. Some of these canals serve extensive regions, sometimes with a catchment of more than 1000 km^2 . This primary canal network of usually regional importance is owned by the state. They are operated and maintained by the governmental district water authorities (DWA-s) under the co-ordination of the National Water Authority. The secondary canals of local importance are maintained by several associations of water management formed by the land owners, while the smaller canals directly serving the cultivated area or settlements are owned by the farmers or communities. If the ‘primary canal network’ is mentioned, further in this paper the state owned canals together with all their structures for water level regulation, pumping stations and other accessories are meant.

Based on the primary canal network a set of so called ‘land drainage systems’ (further LDS) is formed. These areal units follow the catchments of the primary

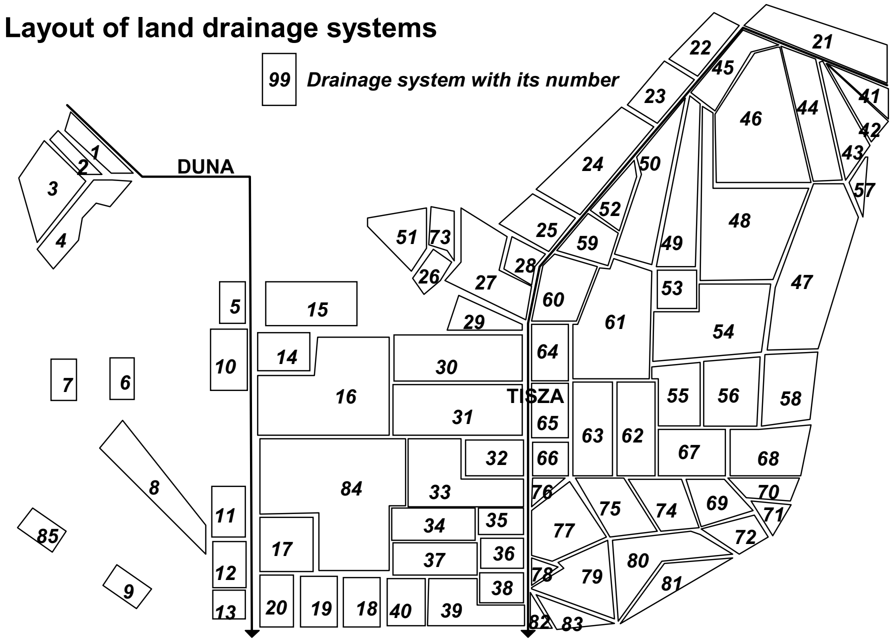

Fig. 1. Layout of land drainage systems

canals as much as possible. Nevertheless, some larger catchments may be subdivided, or in contrary, some smaller neighbouring catchments may be joined. There are all together 85 land drainage systems in the lowland parts of Hungary, their size is 10 – 3000 km^2, with the average around 500 km^2. A sketch of their layout is shown in *Fig. 1*, while *Table 1* identifies them by their name, as well. These units may be considered as hydrologically, hydraulically and operationally homogeneous ones. Though a few systems may reach the borders of hilly areas, their main characteristic is that they have hardly any natural runoff. In case if the layout of the full system requires or makes it possible, they may be split into subsystems. The total number of the subsystems is more than 250.

Several of the primary canals serve also some other purposes, so their management may be influenced by some other interested parties, as well. As most of these lowland canals have almost no bottom slope, and even the direction of flow can be modified by proper operation of structures, a typical ‘secondary’ purpose is to deliver irrigation water in the dry season.

The operation, maintenance and development of the primary canal network with the total length of 11 360 km and numerous structures are governmental task with usually high costs. As the budget cannot fully satisfy all – both short and long term – demands, a well founded, objective evaluation and grading are needed to help decision making. This could be the basis to determine priorities between

Table 1. Name of Land Drainage Systems

No.	Name	No.	Name	No.	Name
01	Szigetköz	30	Gerje-Perje	59	Örvény-Abád
02	Mosoni Danube Branch, right bank	31	Körösér	60	Gyenda-Tiszabő
03	Rábca-Hanság	32	Kécske	61	Hortobágy-Berettyó, right bank
04	Along the river Rába	33	Dongér-Kecskemét	62	Túrkeve-Mezotúr
05	Érd-Dunafüred	34	Dongér-Halas	63	Mesterszállás-Bartapuszta
06	Kis-Balaton	35	Vidreér	64	Fegyvernek-Szajol
07	Nagy-Berek	36	Percsora-Sövényháza	65	Cibakháza-Tiszaug
08	Sió-Nádor-Kapos	37	Algyő	66	Hármas-Körös, right bank
09	Along the river Dráva	38	Tápé-Vesszős	67	Gyoma
10	Adony-Ercsi	39	Gyála	68	Holt-Sebes-Körös
11	Bölcske-Bogyiszló	40	Körösér	69	Kettős-Körös, right bank
12	Szekszárd-Báta	41	Between Tisza and Túr	70	Hosszúfok
13	Kölked-Béda	42	Between Tisza, Túr and Szamos	71	Between Fehér- and Fekete-Körös
14	Along Ráckevei (Soroksári) Danube Branch	43	Between Szamos and Kraszna	72	Élővíz canal
15	Gyál	44	Kraszna, left bank	73	Along the river Zagyva
16	Danube Valley, north	45	Felsőszabolcs	74	Mezőberény
17	Sárköz	46	Nyír	75	Dögös-Kákafok
18	Kígyós	47	Kálló-Alsónyírvíz	76	Hármas-Körös, left bank
19	Igal	48	Along the Eastern Main Canal (Keleti-főcsatorna)	77	Kurca
20	Mohácsi (Margitta) Island	49	Hortobágy	78	Mártély
21	Bereg	50	Along the Western Main Canal (Nyugati-főcsatorna)	79	Tisza-Maroszug
22	Bodrogköz	51	Rekettyés	80	Samson
23	Taktaköz	52	Tiszafüred	81	Élővíz
24	Hejő-Csincse-Laskó	53	Ágota	82	Újszeged
25	Hanyi-Sajfok	54	Hamvas-Sárrét	83	Maros, left bank
26	Felsőszászberek	55	Réhely	84	Danube Valley, south
27	Millér	56	Szeghalom	85	Along the river Mura
28	Doba	57	Ér	–	
29	Zagyva, right bank	58	Between Berettyó and and Sebes-Körös	–	

the regions or between the different intervention possibilities, and sometimes also between the different interests.

The evaluation and grading should be based on such a technical-economical analysis, that

- is uniform over the full country, though it should also contain the local differences e.g. in morphology, natural water courses, land use, ownership, etc., to ensure an objective comparison;
- is based on such reliable data that is present at the regional water authorities or other governmental bodies, or in case of non registered data it can be reliably estimated, and their revision is simple;
- gives a well founded basis for the decision making e.g. to determine which drainage system needs an urgent intervention, or which one requires ‘only’ a careful maintenance, etc.
- in case of multifunction canals gives priorities and determines the rate of interests;
- is understandable and acceptable for all the interested parties within the field of land drainage and out of it, as well.

The purpose of this paper is to introduce a method for the evaluation and grading of lowland drainage systems. After giving the basic principles of the method, a set of indexes is presented. Each index reflects a specific characteristic of the given land drainage system, e.g. its service level, its usefulness, its profitability, etc. to give a basis for the grading to set priorities of different aspects.

For the application of the method a data base and an evaluation program ‘BELREND’ (an abbreviated form of ‘BELvízRENDezés’, i.e. land drainage) is also developed. The program is organised on the subsystem level, but gives also all the information for the full LDS. The data base is assembled with the assistance of the DWA-s, 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, several references will be made on it, especially in case of data requirements.

2. The Method of Evaluation and Grading

2.1. Basic Principles and Data Requirement

The method aims to give a basis for the uniform technical-economical analysis of the development of state owned lowland drainage establishments, to estimate their efficiency in the protection against insufficient runoff over the catchments (VARGA, 1996).

As the method must be uniform over the whole country, it is based on such global information, that is comparable all over. Therefore it does not directly consider the local runoff process, it rather focuses on

- the excess water due to insufficient runoff, that causes or may cause inundation,
- the performance of those canals, which may prevent or reduce inundation,
- the damages caused by inundation.

In this section those parameters are introduced, which may describe these three main items. Most of them may be defined similarly for larger units (e.g. a full LDS) on global scale and for smaller units (subsystems or individual canals) on local scale, but at some points there may be some differences, as well.

As the scale of the method is mainly based on the system/subsystem level, it uses such data, that

- reflect a general characteristic of the area,
- are not subject to continuous changing, causing instabilities,
- give a long term, reliable information, if possible registered at different authorities,
- no continuous measurement is required,
- are easy to reach or reliable to estimate.

Therefore the following data are required for each subsystem:

- total area of the catchment, to describe the size to be served or protected,
- area of settlements and outer area, cultivated and non-cultivated area (e.g. roads) to give a view about the land use,
- average specific productivity of the area given in ‘golden crown’ for hectares (ak/ha),

  > Golden crown is a historically developed unit to characterise the value of fertile area. It is generally used in Hungary and registered at the authorities.

- average mean depth of ground water, characteristic for the region,

  > Average mean is considered to be a regional average of long term mean values.

- average mean runoff coefficient for the winter–spring period and for the growing season,

  > The full year is split into two parts, as the sensitivity against inundation and damages are reasonably higher in the growing season.

- discharge capacity of the canals at the mouth, taking also into consideration the guaranteed intakes and outlets from or to other catchments (systems),
- storage and other water retention possibility over the catchment,

  > Storage is considered as reservoirs with the primary function of storing excess water, while water retention means other possibilities to keep water on the catchment, e.g. in fishing ponds, as secondary purpose.

- total length of primary canals,
- travel time of water in the canal from the furthest part of the catchment to the recipient.

As an example, a data sheet of LDS 61, Hortobágy-Berettyó right bank, subsystem 61/b is given in *Table* 2.

> The list of data in *Table* 2 does not have a continuous numbering. The missing items are not data to be given, but parameters calculated from the given ones.

Table 2. Data sheet of BELREND

1. No. of LDS: 61	Name: Hortobágy-Berettyó, right bank		
2. No. of subsystem: 1	Name: 61/b		
3. Total area of catchment		[km^2]:	343.6
4. Area of settlements		[km^2]:	1.5
5. Outer area		[km^2]:	342.1
6. Cultivated area		[km^2]:	239.0
7. Area out of cultivation		[km^2]:	103.1
9. Average specific productivity		[ak/ha]:	4.70
12. Average mean depth of ground water		[m]:	1.5
13. Average mean runoff coefficient for the winter–spring period. ..		[-]:	0.220
14. Average mean runoff coefficient for the growing season		[-]:	0.110
15. Discharge capacity of the canals at the mouth		[m^3/s]:	12.000
16. Guaranteed intake from other catchment		[m^3/s]:	0.000
17. Guaranteed outlet to other catchment		[m^3/s]:	0.000
20. Retention possibility		[m^3]:	0
21. Storage possibility		[m^3]:	2260000
22. Total length of primary canals		[km]:	106.656
23. Travel time in the canal		[day]:	1.4

2.2. Performance and Density of Primary Canals

The *performance of a canal* at a given section x [m] (usually at the recipient) is considered to be the amount of water, $Q(x)$ [m^3/s] that the canal can deliver under the following conditions:

- average hydraulic parameters,
- average maintenance conditions,
- no inundation along the full canal,
- quasi steady state flow.

This performance may be defined under several circumstances, like:

- ‘present’ situation, taking into consideration the parameters of the canal at a certain moment,
- nominal situation, with values appearing in its licence,
- future situation, after some intervention, with planned or estimated parameters.

In case of perfect maintenance the first two performance values should be the same, while the third one may refer to the profitability of a certain development.

Specific performance is considered to be the above value for a unit area of catchment,

$$q(x) = \frac{Q(x)}{A(x)},$$

where

A [km^2] : size of the catchment, the area from where water due to precipitation will reach the section examined.

Specific performance is actually the discharge capacity serving a unit area of catchment.

Density of primary canals is defined as the ratio of canal length L [km] and area of catchment $A(x)$ [km^2] above the given section x [m] as follows:

$$c(x)\ [\text{km/km}^2] = \frac{L}{A(x)}.$$

This parameter describes how the primary canals can be reached. If the density is low, the primary canals are far away from most parts of the catchment, the water has a long travel time as surface runoff and in ditches or secondary canals until it reaches the primary canal. On the other hand, in case of high density the primary canals are easy to reach, so the travel time is much shorter.

Performance and density together characterise the drainage network that should eliminate or reduce the damages. They are strongly connected to each other, as a high performance is not enough, if the canal is not within reach, or a high density with a low performance may also be insufficient.

2.3. *The Risk of Hazard on the Catchment*

To describe the *risk of hazard* on the catchment the following items are considered:

- precipitation and concentration conditions on the catchment on a global scale,
- performance of the primary canals,
- topographic conditions, which take local characteristics also into consideration.

The estimation of precipitation is based on the guidelines of the National Water Authority (MI-10-451-86), which describes the 20% probability precipitation for small (1–5 km^2) catchments with the accuracy of ±10% for all Hungary. This precipitation is as follows:

winter–spring period: $h\ [\text{mm}] \cong 30T^{0.416}$
growing season: $h\ [\text{mm}] \cong 45T^{0.275}$

where:

$T(x)$ [day] : duration of precipitation, $T(x) = t(x) + \tau(x)$;
$t(x)$ [day] : duration of inundation above section x;
$\tau(x)$ [day] : travel time in the canal.

In case of larger catchments the precipitation has to be modified with a factor $\beta(\beta \leq 1)$ which takes into consideration that the precipitation may not be simultaneous over the full catchment.

The probability factor for precipitation is as follows: $\delta(p) \cong 1.83[1.0 - 0.95(p - 0.01)^{0.308}]$.

The runoff coefficient may also be estimated based on the former guidelines, with the help of the mean average groundwater level. Different values are used for the winter–spring period (α_1) and for the growing season (α_2). In the case of this parameter the 50% probability value is applied.

Taking into account all the above considerations, and also the performance of the canal, modified with the storage and retention capacity $V(x)$ [m^3] over the catchment, *the probability of inundation* of certain duration above the given section x [m] is as follows:

winter–spring period:

$$p(x,t) = 1.18\left\{\frac{1 - \left[Q(x) + \dfrac{V(x)}{8.21 \cdot 10^4[t(x) + \tau(x)]}\right][t(x) + \tau(x)]^{0.584}}{0.64 \cdot \beta(x) \cdot \alpha_1 \cdot A(x)}\right\}^{3.247} + 0.01$$

growing season:

$$p(x,t) = 1.18\left\{\frac{1 - \left[Q(x) + \dfrac{V(x)}{8.21 \cdot 10^4[t(x) + \tau(x)]}\right][t(x) + \tau(x)]^{0.725}}{0.95 \cdot \beta(x) \cdot \alpha_2 \cdot A(x)}\right\}^{3.247} + 0.01.$$

Using the data of LDS 74, Mezőberény, subsystem 3 as an example, both the above functions are demonstrated in *Fig.* 2.

A careful examination of these formulae and graphs shows that the winter–spring period seems to be the more unfavourable, as its higher precipitation requires a higher performance, or causes a longer inundation. But on the other hand, an inundation in the growing season can cause greater damages.

This global approach sets a connection between the duration of inundation and its probability, but gives no direct information about the size and location of inundation. But based on the above information, the volume of water causing the inundation can also be estimated. As it is connected to a given inundation time of certain probability, the probability of this volume is also given. Based on a detailed topographic map, the volume-level and the area-level connections of the region can

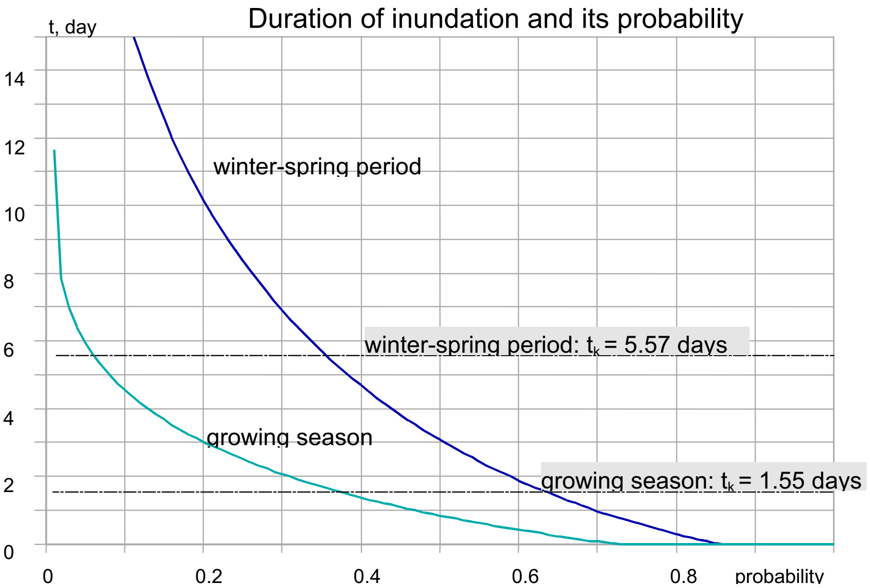

Fig. 2. Duration of inundation and its probability

be determined, which will give the level and area of inundation for a given volume. Then the inundated parts of the catchment can be looked up on the map with the help of the contour lines. This is how the global approach can be transferred to local scale.

The *risk of hazard* of inundation on a certain catchment due to the insufficient performance of the canals can be characterised by the mean average parameters,

- on global scale the *mean average inundation time*: $\bar{t}_k(x) = \int_0^1 t(x, p)\,\mathrm{d}p$. This value for both periods is also indicated in *Fig.* 2.
- on local scale the *mean average inundated area*: $\overline{A}_e(x) = \int_0^1 A_e(x, p)\,\mathrm{d}p$ and the inundation time together.

> The average value refers to the average performance of primary canals, while the mean value is considered as the same frequency of exceedence and non-exceedence.

Mean average inundation time and area defined in the above way characterise a general level of hazard on the catchment.

2.4. Sensitivity of Catchments Against Damages

The magnitude of damages on a lowland catchment is determined by

- the land use and its variation over the catchment,
- the productivity of agricultural areas,
- the performance of drainage network with its accessibility and density,
- time, duration and frequency of inundation due to limited or insufficient performance of the canal network.

To describe the sensitivity against damages it is recommended to take such a well established parameter into account, that can be considered as constant for a longer time extent, and is not influenced by seasonal or short term economical changes. Therefore the traditional *specific productivity* in golden crown for hectares, a [ak/ha] is used. This is an overall used and accepted parameter to describe the specific value of a certain piece of land. It is officially kept for agricultural areas at the cadastral register. *Productivity* of a certain area is then coming from the specific productivity and the area, $AK(x)$ $[ak] = a$ [ak/ha] $\cdot$ A [ha].

The above approach may be valid only for agricultural area. For the full catchment with all the settlements, roads, etc. a weighted average, $\overline{a}$ [ak/ha] (usually $\overline{a} > a$) is defined. In such a specific value those non-agricultural areas of high importance are taken into consideration with an estimated weight.

Virtual productivity, $\overline{AK}(x)$ [ak] of the area is then defined as the product of $\overline{a}$ [ak/ha] and the full area. In this product the fertile land is taken into consideration with its real value, while other areas are considered as virtual fertile land instead of villages or roads with an estimated specific productivity.

The above way may be used on global scale, where the inundated area is a general quantity. In case of local examination, where the inundated area, $\overline{A}_e(x)$ and its location is also defined, instead of virtual productivity, the actual productivity of that certain area should be applied.

The virtual productivity can be determined for a given section of a canal. This can be considered as the value, that the canal itself protects, and this may be reduced in case of inundation. Of course the damages may be influenced by the way of cultivation, the type of crops, etc., but in this point the aim is not the estimation of the actual loss, but rather to give a general formulation for the extent of real or possible damages.

Beside the value of the protected area, the time and duration of inundation is also of basic importance. Especially the growing season is sensitive for inundation, while in the winter–spring period a short inundation may have no, or sometime even positive effects, e.g. groundwater recharge after a long dry period, as well. Therefore the inundation in the growing season is taken as major parameter, though the winter–spring period cannot also be left out of consideration. The damages are taken into account as follows:

- without inundation, there is no damage,

- in the growing season the area is totally damaged (i.e. no yield can be expected) after $\overline{t}_{kg,\max} = 4$ days of inundation;
- in the winter–spring period the area is totally damaged after $\overline{t}_{kw,\max} = 10$ days of inundation;
- between the inundation of zero and $\overline{t}_{k,\max}$ days, the extent of damage varies linearly.

If the index g or w is not indicated, as in the last point above, the notation of mean average inundation time or other parameters refers to both the winter–spring period and the growing season together.

Finally, the *sensitivity of a certain catchment against damages* above the certain section x [m] due to an inundation of certain duration can be defined as follows:

$$K(x)\ [\text{ak/ha}] = \frac{\overline{t_k}(x)}{\overline{t}_{k,\max}}\overline{a}(x), \qquad \text{if } \overline{t_k}(x) < \overline{t}_{k,\max},$$

$$K(x)\ [\text{ak/ha}] = \overline{a}(x), \qquad \text{if } \overline{t_k}(x) > \overline{t}_{k,\max}.$$

This is actually the damage formulated in specific productivity. It describes what damages may be expected due to the hazard defined in point 2.3.

3. Set of Technical-Economical Indexes

3.1. General Remarks

Based on the parameters of point 2 a set of technical-economical indexes may be defined. These indexes describe several characteristics of the catchment, as

- what level of service the land drainage network provides,
- what benefits may be expected if they are properly maintained and operated,
- if they are sufficient in the present situation, or if they need some development,
- which catchment is more interested in certain intervention.

Those indexes, which are expressed in natural quantities, are called the absolute ones, while those, which are normalised, given in percentage 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.

Though all the indexes have a real physical meaning, most of them do not have an absolute scale. If one single unit (LDS, subsystem, etc.) is characterised with one single value, it is almost impossible to decide if it is high or low. But this certain value can be compared to that of another unit, with a regional average or an extreme value, and then several conclusions may be made. That is how these indexes can provide a useful tool for comparison and decision making.

All the indexes may be determined separately for the winter–spring period and for the growing season. If the full year has to be considered, the corresponding indexes can be simply added.

The set of indexes to be introduced cannot be considered as a closed unit, it contains only the basic ones. In case of specific problems some other indexes may also be defined based on the given ones to provide a better formulation of that certain case. This flexibility of the method will be demonstrated in a later paper of this volume, where some examples will be given for the practical application.

The intervention possibilities mentioned earlier may be the following:

- *Maintenance*, that aims to keep the performance of the system on the level as it is. It is left out of consideration if this performance is lower (or maybe higher) than the one given in the licence, it means only the preservation of that given condition.
- *Reconstruction*, that aims to restore the performance given in the licence of the given canal or structure. Reconstruction may be needed for example if maintenance is insufficient, if an overload due to extreme meteorological conditions damages the canal or its structure or simply after a longer use even if maintenance is proper.
- *Development*, that aims to increase the level of protection with increasing the performance or density of canals or both, with more efficient operation of the structures, etc.

3.2. Index of Service Level

This index describes what safety a certain primary canal provides, how it can be reached and how it may reduce damages. It leaves topographic conditions out of consideration, it may be applied only on global scale. Usually its reference section x is at the recipient of the primary canal, $x = 0$. This recipient is mainly a river or a lake, or sometimes a so called regional canal, which serves multiple purposes and also several land drainage systems, so it is considered to be out of any LDS. It is assumed, that this recipient can divert the full amount of water delivered by the primary canals, the examination of their capacity is left out of consideration. The *service level index* is as follows:

$$S\ (x=0)\ [1/\mathrm{km}] = \left[1 - \frac{\overline{t_k}\ (x=0)}{\overline{t}_{k,\max}}\right] \cdot c\ (x=0), \qquad \text{if } \overline{t}_k\ (x=0) < \overline{t}_{k,\max},$$

$$S\ (x=0)\ [1/\mathrm{km}] = 0, \qquad \text{if } \overline{t}_k\ (x=0) > \overline{t}_{k,\max}.$$

If there is no inundation, the service of the canal network is perfect so the service level is the same as its density. If the duration of inundation is limited, then the service is reduced which is described with a reduced density, while above this duration the service is insufficient.

3.3. Index of Usefulness

Index of usefulness is an absolute quantity. It shows how the service provided by the canal is utilised to reduce damages. It may be defined as specific and total index.

Specific index of usefulness referring for section $x = 0$ may be defined in two ways, which numerically give the same value. It is as follows:

$$h\ (x = 0)\ [\mathrm{ak/(ha \cdot km)}] = S\ (x = 0)\ \overline{a} = [\overline{a} - K\ (x = 0)] \cdot c\ (x = 0).$$

The index shows what value given in specific productivity is protected by a unit length of the canal.

The first way of definition means that the full value is protected by a network of certain service level. If the service level is low or zero, the value of a is not properly protected, so the benefits of operating the system may be questioned.

The second way means that the given canal network with the density of $c(x = 0)$ may protect only a reduced value. If the area is not sensitive against damages, i.e. $K = 0$, the canal network is suitable to give a full protection, while if K is high, maybe as high as a, the network is not suitable to serve the region.

The specific index of usefulness applies the specific productivity, which refers for a unit area of the catchment. But sometimes it may be of decisive importance how large the full catchment under examination is. Maybe an intervention on a larger catchment will provide a greater return, or in contrary, the limited resources may cover the costs of a smaller catchment. Therefore beside the specific index, the *total index of usefulness* is defined as follows:

$$H\ (x = 0)\ [\mathrm{ak/km}] = h\ (x = 0) \cdot A\ (x = 0) \qquad \text{in global approach,}$$
$$H\ (x = 0)\ [\mathrm{ak/km}] = h\ (x = 0) \cdot A_e\ (x = 0) \qquad \text{in local approach.}$$

Both the specific and total indexes reflect how a canal network serves its purposes under certain (present, nominal or future) conditions. If the index of usefulness is high, that means a good service, therefore it is recommended to maintain it as much as possible to keep this advantageous situation as long as possible. So in case of such systems, maintenance is of exceptional importance. On the other hand, a system with poor or zero usefulness shall never return the costs of maintenance, it requires other intervention.

It may also be an important point in decision making to compare the indexes of usefulness referring to a given ‘present situation’ and to the nominal parameters. The difference between the two indexes refers to the necessity of reconstruction. For example, an LDS with high nominal and low or zero present h or H index needs an urgent intervention to restore its original (nominal) conditions, because it protects a valuable area.

As resources are usually limited, even among systems or subsystems with high usefulness a difference should be made. Therefore a normalised index is defined to show which system or subsystem has the most or less interests in maintenance.

This relative index is *the interest index based on usefulness*, which is as follows:

$$R_H\ [\%] = \frac{H_i}{\sum\limits_{i=1}^{n} H_i} \cdot 100,$$

where:

n: total number of units in the whole (e.g. systems in the country or subsystems in an LDS).

The interest index may be defined within a given LDS for the subsystems, for several systems in a larger region or for the full country. It shows what rate of interest in the whole a certain unit has.

3.4. Index of Demand for Development

Index of demand for development is an absolute quantity. It shows the level of insufficient service provided by the canal. Its name reflects that a system with poor service requires development. It can be considered as the opposite of the index of usefulness. It may be defined as specific and total index.

Specific index of demand for development referring for section $x = 0$ is defined as follows:

$$f\ (x = 0)\ [\text{ak/ha} \cdot \text{km}^2/\text{km}] = \frac{K\ (x = 0)}{c\ (x = 0)}.$$

The index shows what value given in specific productivity is damaged in a certain area described with its canal density. In case of low or no sensitivity against damages, even a sparse canal network may be enough which gives a low demand for development. On the other hand, if high damages are expected with high K value, the same network cannot fully protect the area, so development is needed.

Similarly to the index of usefulness the *total index of demand for development* may also be defined. It is as follows:

$$F\ (x = 0)\ [\text{ak/(ha} \cdot \text{km)}] = f\ (x = 0) \cdot A\ (x = 0) \quad \text{in global approach,}$$

$$F\ (x = 0)\ [\text{ak/(ha} \cdot \text{km)}] = f\ (x = 0) \cdot A_e\ (x = 0) \quad \text{in local approach.}$$

Also, the normalised *interest index based on the demand for development* can be determined to give priorities between the different systems:

$$R_F\ [\%] = \frac{F_i}{\sum\limits_{i=1}^{n} F_i} \cdot 100.$$

In case of high index f, F or R_F , the development of the drainage network is needed, which may be the following:

- the establishment of new canals to increase density,
- the enlargement of existing canals to decrease inundation,
- the enlargement of storage or water retention possibility,
- the examination of outlet possibilities to other catchments, if it will not reduce service safety there,
- the reduction of intake from other catchments, if there is any, etc. or their combination.

It is mentioned earlier, that in a certain sense, indexes H and F are the opposite of each other. It means, that a catchment with high usefulness is interested in maintenance to keep this pleasant situation, and it does not need any further development. On the other hand, a catchment with poor usefulness will never be better even with the best maintenance, it requires development. From the point of view of demand for development, a high F value means an insufficient network, which can only provide safety against inundation after certain development. And the low F value means, that in the examined situation the catchment can be considered as safe, and this pleasant situation must be kept as long as possible with proper maintenance. So high F value usually goes together with low H value, and low F value is connected to high H value, though in some special cases other considerations may also play an important role.

3.5. Index of Economic Efficiency

The index of economic efficiency aims to set an objective parameter for the comparison of the profitability of different development possibilities of the primary canal network. For its determination the following basic assumptions are made:

- the planned development will increase the performance of the given canal,
- the yield of the investment appears mainly in the agriculture.

The *relative index of economic efficiency* is actually the damage on the catchment that can be avoided due to that certain investment. It takes both the single costs of development and the continuous extra costs due to usually higher maintenance requirements and national economic norms also into consideration. It is determined for a longer time extent, usually for several years.

The relative index of economic efficiency can be determined in the following way:

$$g\ [\mathrm{Ft/(ak \cdot year)}] = \frac{B_0}{\overline{a}\ (x=0) \cdot A\ (x=0) \left(\dfrac{\Delta \overline{t}_{kw}}{\overline{t}_{kw,\max}} + \dfrac{\Delta \overline{t}_{kg}}{\overline{t}_{kg,\max}} \right)} \times \left[\frac{1}{15\ \text{years} - (j_b + 1\ \text{year})} \pm \frac{U_0}{B_0} \right],$$

where:

B_0 [Ft] : costs of development in the year of decision making;
U_0 [Ft/year] : the increment or decrement of maintenance costs due to the development compared to the original maintenance costs in the year of decision making;
$\Delta\bar{t}_{kw}$ [day] : the decrement of mean average inundation time due to the given development in the winter–spring period, with the maximum of $\bar{t}_{kw,\max}$;
$\Delta\bar{t}_{kg}$ [day] : the decrement of mean average inundation time due to the given development in the growing season, with the maximum $\bar{t}_{kg,\max}$;
j_b [year] : number of years between decision making and the end of the planned development;
15 years : estimated lifetime of the investment.

The more efficient an investment, the smallest the index g should be. As index g contains also the mean average inundation time, it is the function of the performance (present and planned) of the given canal. If it is determined with different planned capacities, g will show a minimum. The planned capacity of this minimum value can be considered the optimum of the canal.

The *absolute index of economic efficiency* compares the costs and the benefits of the investment. In this case the benefit is considered to be the extra yield due to the reduced inundation. The yield is formulated in corn equivalent tons which is a virtual yield taking into consideration crop distribution transformed to wheat. The index is the following:

$$G\ [\text{Ft/Ft}] = \frac{1}{g} a_{ge} \cdot e,$$

where:

a_{ge} [Ge t/(ak · year)] : mean average corn equivalent tonnage of a unit productivity in a year;
e [Ft/Ge t] : the price of a unit yield.

Index G shows the yearly ratio of costs and benefits. The higher index G refers to a more preferable investment. An investment can be considered as efficient with the index higher than 1. This seems to be a relatively low value, but it is due to the relatively short lifetime (15 years), which is unusual in case of other infrastructural investments.

The same indexes of economic efficiency may be applied not only for development, but for reconstruction. In that case the present and the nominal parameters have to be taken into consideration while determining the reduction of inundation.

The index of economic efficiency may be applied to evaluate investments with different parameters on a certain areal unit, but also for the comparison of investments on different regions.

4. The Application Possibilities of the Method

The present paper introduced a method for the grading 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. These indexes are defined so, that they are

- based on well founded data, registered at authorities to give objective information,
- describe the most important technical-economical characteristics of the canal network,
- applicable all over the country,
- show what kind of intervention (maintenance, reconstruction, development) a certain region needs,
- show the interest rates of the different users of the canal network in a simple and clear way,
- show economic efficiency of investments;
- flexible to determine, they take always into consideration what the task is, what the available data are, etc.
- gives help for the decision making process with giving the priorities between
  - the different regions of the country,
  - different intervention and investment possibilities,
  - different interested parties.

Though it is never the only aspect to be considered, it has a wide range of application possibilities. A later paper of this volume gives detailed case studies, here only some examples are given to demonstrate it, as follows:

- By the time of the national level introduction of the method it is of basic importance to lay down the ‘initial’ parameters of the areal units (LDS or subsystem) to give a basis for the later comparison. Such a survey to determine all the indexes of usefulness (H, h and R_H) and demand for development (F, f and R_F) and to set the grades of the units may prove the long term experience on the operation of the individual units, though it may also give some unexpected results as well. Such a survey may be the basis of the further development of the land drainage network.
- Similar investigation should be done with the nominal parameters of the unit and also with the ‘present’ parameters of that certain time to determine which units need a reconstruction to restore its original performance.

- After some years, especially with extreme hydrological conditions (wet period or drought) or with larger investments, or even after a period with no investments, just with maintenance, it is worth to update the indexes to see their variation in time.
- In case of limited budget for the investments, the indexes may show
  - which areal unit needs the most urgent intervention, and which ones may be scheduled for a later time,
  - which unit provides the most effective investment with the highest return.
- In case of a given investment on a certain unit several versions of the intervention may be examined to find an optimum.
- In case of extreme hydrological conditions over a region, it may be expected, that a certain recipient cannot serve the full larger region without overloading. Such an approach may help to decide which unit of this region should suffer some damages in order to ensure safe conditions over another unit of higher value.
- In case of multiple purpose canals this set of indexes may determine the importance of the individual purposes which may provide basic information for the operation and development.

Finally, it has to be mentioned, that similar set of indexes may be defined not only for the land drainage network, but also for irrigation systems on the lowlands, and also for hilly catchments. Though they have already been elaborated, in the field of their application there is not yet such a wide range experience.

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