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Design and Operation Principles of Hydraulic Headwater Structures (Weirs, Barrages and Dams)

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Summary

The results of author's method for evaluation of water levels (and discharges) instability as the function of time are described and new Environmental Classification of water headworks is proposed, based on water flow velocity criterium and application the "instability factors" for determination save water levels elevations (and outlet works discharge conveyance capacity), accepted for design and valid for the whole project life period.

The classification is based on the assumption, that local channel processes and risks (biological, erosion, sedimentation, ice control and other's) within the environment of hydraulic works will be eliminated or negative impacts limited. The main aim of applied classification is to protect the hydraulic water-head structures from degradation, aggradation and deterioration. The general specification for design of discharge capacity of spillways and outlet works determination are given, as well as the main principle of the investments management.

The general and particular technical requirements are specified for mitigation the negative impacts on the hydraulic headwater structures, as well as structures influences on the environment.. The scope of required changes in regulations and specifications are given to include in the present polish regulations and standards, including European EC7 Standard.

Keywords: Erosion, sedimentation, works classification, specifications, design criteria, management.

1. INTRODUCTION

Safety of lands against floods is depending on the extent of sediment transported along the river channels.

Sediment control is a function to be included in plans for land and water resource development. Sediment is the product of erosion and consists of organic and inorganic un-dissolved solids. It may be transported as suspended load and bed load in flowing water, or may be transported by wind. The following may result in the production of sediment:

- 1) The action of water concentrated in gullies, intermittent streams and water courses; and
- 2) raindrop splash on exposed soil.

Sedimentation results in

- The silting of reservoirs and stream channels,
- Aggravates flooding and flood damages and
- Influences the usability of water supplies.

Damaging sedimentation can be best reduced by programs of land treatment or erosion control practices farm, range and forest lands

as well as structural measures needed in water flow-retardation systems.

It is assumed that erosion-control practices are generally preferable to other methods of reducing sediment damage because they remove the basic cause of the damage and benefit both the areas of erosion and the areas of sedimentation amount of soil carried away by runoff and minimize the harmful effects.

The functional studies having a major interest in sediment control are water supply, navigation, irrigation, forest and soil conservation and utilization, fish and wildlife, recreation, flood control and pollution abatement.

Unsuccessful attention have been diverted during last decades to the problem of unstability of flow parameters, observed within the existing erosive river channels during operation of hydrotechnical head-water structures.

The recent polish technical, as well as foreign publications do not contain information on **variability of water flow parameters**, observed during a life of the projects, and their influence on the

investment's safety during the Project life.[Naprawa, 1986, 2002,2012, 2017, 2018].

This variability of water flow parameters is the result of existence the geomorphological processes, described in detail in many available books on geomorphology [Klimaszewski, 1978 and many others].

All existing hydraulic structures located in the rivers channels or within adjacent valleys are loosing with time their required and designed discharge conveyance capacity. As the result we can observe presently more frequent uncontrolled floodings, in majority cases due to the flood levees crests over-topings (Naprawa, 1997, 2010).

The existing hydro-complexes are maintained in changed hydraulic conditions. The water stages related to the selected specific discharges, through the selected years and time intervals are generally changing vertically, increasing or decreasing, as the case may be resulting from local soil and water flow conditions. Thus the adopted design criteria. can not be satisfied. As the result the structures (regulators, weirs, barrages, dams) are maintained in different local conditions and do not conform to the required approved design criteria and working conditions. The structures do not operate in expected planned functions at safe water pools., Flood waters are frequently overtopping the levees crests leading to the floodings the areas envisaged to protection. [Naprawa, 1997, 2010].

The situations described above should be taken into consideration during the design. To allow the designers complete their calculations in a proper way, the **existing regulations for design must be revised, amended and approved by he government authorities.**

The water flow parametres which are subject to change during operation of hydraulic systems are;

- Shape and scoss-section of wetted perimeters Of the channels,
- Flow velocity,
- Longitudinal water slope,
- Hydraulic radius,(water depth), and
- Soils physical and mechanical parameters.

According to previously completed studies [Ionides 1938; Lane, 1955; Kennedy, 1963; Koban@ Kornacki, 1968; Ackers, 1970; Sundborg, 1986; Babiński, 1982, 1992, 2017 ; Naprawa 1987, 1997, 2002, 2012, 2014, 2017; 2018; ILH 2013] we can conclude, that serious lack of care exist about necessary revision of existing headwater structures regulations and specifications, conforming to the actual dangerous situation observed in floods control. Clear relation exist between the changes of unstable water flow regimes in erosive river channels and river flow parameters assumed by the designers in the Design Critea. Due to fact that structures are working in changed conditions, their operation contradicts with approved basic design criteria. The negative and destructive influences of erosion, sedimentation and sediments transport along the river channels were already recognized and call for immediate undertaking the remedial actions. The proposals presented in this paper wait for consideration and should be introduced to practice as soon as possible. The negative processes observed within the rivers channels are destroying the designed relations between flow

parameters and actual different situations observed must be taken into consideration at the initial stage of design process.

Thus the negative impacts of the environment from the geomorphic flow regime, as well as other regimes (biologic, chemical and thermal affecting the quality of water) may be limited or even eliminated. These problems related to the quality of water are very important for the water supply for municipal and domestic purposes, as well as for the industry and agriculture.

2. BENEFITS FROM CANALIZATION OF RIVERS FOR SUSTAINABLE DEVELOPMENT (IMPROVEMENT OF AGRICULTURE, NAVIGATION, FLOOD CONTROL AND WATER ENERGY PRODUCTION)

The benefits from canalization of rivers can be specified as follows;

1. The water pools created can be utilized for the construction of hydraulic water plants and water intakes for the industry, agriculture and municipalities inhabitants in towns and villages).
2. The cascade of water stages ensure the water supplies for all water users. The additional water retention is available without costly expropriations.
3. The stabilization of low water levels at selected most convenient pools along the valley protects adjacent areas against desertation (over-drying) and change negative the impacts of a bottom and side erosion.
4. The aerial influence of the cascades is significant, what enables a ground water percolation processes to the areas lying in depressions, reconstruction of aquifiers and improvement in ground water supplies.

The canalization of rivers protects the valleys against the winter floods caused by ice dammings.

5. The canalization of rivers improves navigation, ensuring required water depth.
6. The canalization of rivers enables navigation during low water levels , used to while returned ground water discharges can be utilized for lockages and evaporation losses..
7. The navigation season can be longer, as the waterway is independent from the rainfalls. The only limitation is an influence of ice phenomena
8. The canalisation enables the control the geomorphic processes retated to the sediment transport – decreases erosion, allows for application of sediment flushing, and decreases the volume of dragging works practices
9. Specified above benefits allow the construction of the hydrotechnical complexes required fpr sustainable development of regional importance.
10. The positive features specified above are creating possibility for the construction of complex investments based on sustainable development policy.

It is worth to note, that in general the existing large sediments transport in rivers is seriously affecting the navigation conditions.

The construction of the headwater cascades may solve the problems and improve situation.

It should be noted that existence of sediments transport in rivers have significant influence on the natural environment and flow conditions.

The discharge intensity flow curves used for design, after several floods are losing their adequacy for design, because main flow parameters are changing with time; viz.: shape and cross-section area of wetted perimeters, longitudinal slope of water surface, as well as its vertical position, due to bottom erosion.

The sedimentation processes observed along the river banks are responsible for continuous increase of water levels (for same specific discharges). It is thus obvious, that NATURE 2000 zones established along the rivers banks should be terminated and new principles for operation and maintenance of developed navigation waterways should be introduced.

3. BASIC PROBLEMS CONNECTED WITH THE CONSTRUCTION OF HYDRAULIC HEADWATER WORKS ON FREE FLOWING RIVERS

The construction of hydraulic headwater works along free flowing rivers constitute a significant impact into the natural environment, changing the natural flow conditions in erosive river channels in unexpected direction. These post construction impacts are of positive, as well as of a negative character. The sedimentation of reservoirs create problems, not always accepted.

The list of problems related to the rivers canalization by the construction of hydraulic headwater works includes the following:

1. Biological processes observed in toxic sediments, limiting the oxygen content,
2. Change of the volume and flow regime of fluvial transport, which is appearing in various forms,
3. Change of the water flow regime downstream the dams axes,
4. Change of the water dynamic flow regime upstream the dams along a backwater lengths, leading to
5. Reservoirs sedimentation, and
6. Decrease of coarse grains quantity,
7. Change of the winter ice flow regime,
8. Change of the quality of a transported dissolved substances,
9. Change of the upstream water geomorphic flow regime of the class E1 in natural conditions (erosion) to the class E2 (sedimentation), or to class E1 (as required by managing staff) [Naprawa, GeoSym2018],
10. Change of the downstream water geomorphic flow regime of the class E1 in natural conditions (erosion) to the class E2 (sedimentation), or to class E1 (as required by managing staff), [Geo&Sym2018],
11. Change of the chemical content of sediments stored in the reservoir upstream the dam,
12. Decrease of suspended sediments concentration, leading to the water quality increase at the intakes,
13. Possibility of maintaining during a navigation period (upstream the dam along the backwater lengths) the

required navigation depth due to staff decision, (flushing as required) [Naprawa,2018]

14. Possibility of maintaining during winter (upstream the dam along the backwater lengths) the required water flow velocity to control the frazil ice transport and convey the frazil ice with water thru the outlets downstream (as required after lowering the upstream water pool elevation due to staff decision). It should be noted, that lack control of water flow velocity along the reservoirs can lead to flood events (structures crests overtopings, dikes breaches and uncontrolled floodings, etc.) [Naprawa, 2011].

Construction of hydrotechnical investments (individual water-head structures or series of complexes) constitutes significant impact to the natural flow conditions of river channels. The changes of hydraulic flow conditions in developed river channels can have a positive character, as well as negative.

The positive impacts are:

- The possibility of execution seasonal sediments flushing deposits from the reservoir, what may always be effected after decreasing U.S. Pool elevation of the structure and increase the water flow velocity to values above the critical velocity.

Utilization of movable gates at spillways and bottom outlets for stimulation the required water flow velocity is of great value for safe operation and maintenance of the structures. The only one condition exists related to the structural details of the spillway design: the overflow section of the barrage (or regulator) should be designed without elevated sill. Thus the 50% possibility flood discharges can be conveyed with eroded sediments from the reservoir's area.

The hydraulic head-water structures of environmental class E2 are suitable for removal of sediments. [Naprawa, 1986, 2001, 2002, 2010, 2012, 2017, 2018].

The bottom erosion of traditionally regulated rivers have positive character in this case, as the higher navigable water depths are avoidable after flushing of regulated river channel. The barges can navigate at larger depths and at the longer navigation season. The navigation is more economic in this case.

The negative impacts are always observed at the downstream side of a barrages, when bed erosion is always present, affecting the maintenance operations. The extent of eroded zone depends of flow velocities, observed during the operation, and floods seasons. The erosion depth can be limited by the application of safe unit discharge over the outfall apron.

Another negative impact is a ground water horizon decrease within the river valley downstream, leading to desertation of adjacent areas.

Construction of the river cascade improves situation.

The areas adjacent can be irrigated by gravity, protecting the river valley against desertation.

4. NEW APPROACH TO THE DISCHARGE CONVEYANCE CAPACITY EVALUATION OF EROSION RIVER CHANNELS

General

The methodology proposed for design or checking the crests evaluations of flood levees [Naprawa, TKZ2017] can be applied also to the discharge conveyance capacity control evaluation of the river channels.

The expression $H=f(Q)$ - discharge flow intensity curve used for levees crests control may be utilized in reverse direction, e.g. $Q=f(H)$, and taking into account the TIME FACTOR (T_0 - in years) - the INSTABILITY CURVE OF THE CHANNEL DISCHARGE CONVEYANCE CAPACITY IN FUTURE DURING OPERATION PERIOD FOR CONSECUTIVE TIME INTERVALS SHOULD BE PLOTTED, utilising the following equation:

$$Q_T = Q \pm \frac{Q_2 - Q_1}{T_2 - T_1} * T_0 = Q \pm \frac{\Delta Q}{\Delta T} * T_0 = Q \pm S_Q * T_0 \text{ [m}^3\text{/sec]},$$

Where:

Q_T = discharge after T years for specific (constant) water level, e.g. at the end of PROJECT LIFE in m³/sec,

Q = discharge read from the actual discharge intensity curve at the analyzed gauging station cross-section for the year of design - read from the discharge intensity curve supplied by the Hydrological Institute. Two (2) discharges has to be taken into consideration as adopted by the designer during elaboration of the project during design:

- Maximum Probable Flood discharge (M.P.F.), and
- Maximum Design Flood discharge (M.D.F.)

T_1 = year of design date determinating validity of the discharge intensity flow curve e.g. relation $Q=f(H)$, assumed by the designer for the project risk evaluation,

T_2 = end year (date) of the project life, at the of analyzed operation period

$T_0 = T_2 - T_1$ = total project life period, time interval expressed in years from date of design (T_1) to the end of analyzed period (T_2), in years. Short time increments can be analyzed. eg: between consecutive flood events.

$\Delta Q = Q_2 - Q_1$ = change increment in m³/sec of the channel discharge flow capacity (decreasing or increasing) relative to respective specific (constant) water levels = discharge difference value for specific water levels at assumed dates (increasing in case of siltation, decreasing in case of erosion)

$S_Q = \frac{\Delta Q}{T_0}$ = DISCHARGE INSTABILITY FACTOR = corrective coefficient indicating mean annual change intensity of the channel discharge capacity in m³/sec/ during recording period (T_0):

“+” $S_Q > 0$ denotes channel discharge capacity decrease in consequence, that water level after T_0 years in exceeding the water level recorded at the beginning of operation period (or at the date of design T_1 , eg.: discharge conveyance capacity of the channel is decreasing.

“-” $S_Q < 0$ denotes channel discharge capacity increase in consequence, that active cross-section of the channel is increasing during operation period

$T_0 = T_2 - T_1$ due to erosion change of the cross-section shape), thus the discharge channel flow capacity is increa-00posing.

Important conclusions (to be introduced in the Design Code)

The flood discharge capacity of the erosive rivers channels (as well as other flow situations) should be checked by the designers and /or operating staff, taking into consideration the geomorphological changes of the existing channel. The DISCHARGE INSTABILITY FACTOR METHOD should be applied [Naprawa: 1986, 2002, 2012, 2017] and advised methodologies applied, as proposed.

- In case, that designer recognizes, that analyzed cross-section of the river channel is subject to continuous siltation due to existence of the geo-morphological regime - all negative impacts should be identified and analyzed [Naprawa,2017, 2018]
- Recognized negative impacts should be subject to detail consideration, and respective design corrective measures should be applied, e.g.:
 - (a) In case the Mannings “n” factor is excessive, due to lack of care about the areas located between levees and river banks - the general cleaning of this area should be effected, whole area along river banks cleaned and macro-leveling completed.
 - (b) In case, that alignment of the river channel creates hydraulic difficulties during floods periods within the river channel, due to sharp curvatures of channel center line, as well as due to improper hydraulic conditions (e.g. heading up flood water levels along levees crests at bends with to small radiuses of curvatures) - the designated channel should be redesigned and reconstructed respectively.
 - (c) To ensure effective and undisturbed operation of the head-works structures and other hydraulic structures located along the river channels (e.g. flood levees and U.S. side dikes along low-land reservoirs) - the known other methods for combating negative impacts should be applied at the design stage, as well as during control operation period of the head-works, as described and proposed in respective papers [Naprawa: 1986, 2002, 2012, 2017, 2018].

Special attention of the readers is diverted to paper: Methods for mitigation and combating the negative impacts of erosion and sedimentation in erosive river channels - guaranting protection of natural environment [Naprawa, 2012]

5. THE INNOVATIVE ENVIRONMENTAL CLASSIFICATION OF HYDRAULIC HEADWATER STRUCTURES

The negative environmental impacts observed in erosive river channels can be eliminated due to construction of river cascades, consisting of number headwater structures: dams, barrages, weirs, regulators and water distributory canals systems - provided that proposed environmental classification of hydraulic headwater structures will be accepted and applied in practice [Naprawa,2017, 2018].

The main purpose of establishing the environmental classification for hydraulic headwater investments is to combat the negative impacts of geomorphic regime existing in erosive rivers channels.

Taking into account the necessity for ensuring the safe operation conditions of headwater hydraulic water control facilities (reservoirs, outlets, spillways, revetments, dikes, etc. used for water storage and conveyance) all hydraulic headwater structures should be divided into three environmental classes viz.:

- ✓ **Class E1:** includes the hydraulic head structures operating at a stable geomorphic regime. The sediment balance is nearly zero ($v \approx v_{crit}$); (stable or apparently unstable regime). The irrigation canals supplying silt laden water should conform to the requirements of class E1 [Lacey theory; Naprawa, 1986].
- ✓ **Class E2:** headwater structures are the flows of erosive type, enabling for operation at selected upstream water elevations (as decided by the operating staff and as required), and ensuring required discharge capacity of outlets and spillways (as decided by staff)
- ✓ The construction of the structure of class 2 ensure to maintain [Naprawa, 2012, 2017]
 - Stable flow regime, ($v \approx v_{crit}$),
 - Erosion type regime ($v \geq v_{crit}$),
 - Sediment type regime ($v \leq v_{crit}$);
- ✓ **Class E3:** Comprises the head water structures of sediment type flow regime ($v < v_{crit}$). [Naprawa, 2018].

The positive feature of the structures classified to the environmental class E2 is the possibility of decreasing the free tractive forces to safe level, and their effectiveness in reduction the extent of destructive erosion within the river channels.

Hydraulic conditions are maintained at Class E2 structures in accordance with the planned operation schedule at the stage of design. The destructive impacts resulting from appearance of excessive potential free tractive forces acting during the floods can be decreased due to application various upstream water pools, reducing the actual tractive bed forces to safe values.

Above water flow conditions may be created, when the structure is designed without high elevated sill at the openings used for flushing practices, within a whole range of U.S. water levels pool fluctuations.

The aim of described above flushing practices is to enable maintaining continuous sediment control along the backwater length of the reservoir.

The hydraulic headwater structures are in general used for the purpose of water storage and control of discharges. At normal operation cases the system is operated at sedimentation type regime, with flow velocities below the critical values. To control the sedimentation the flushing procedure must be effected when required during floods, provided the flow regime of erosive type is possible to be created by application the lowered U.S. water pool, at the increased bed flow velocities close to the critical, enabling the movement of soil grains deposited along the wetted perimeter ($v > v_{crit}$). The deposits stored in the reservoir can be moved and flushed away downstream, as decided by the operating staff. Seasonal flushing practices can be considered at the best available method for sediment control, extending the Project life.

The reservoirs of class E3 create inconvenient biological and chemical conditions, detrimental to the water quality. It is therefore

advised to reconstruct the existing structures of class E3 to the class E2.

It should be emphasized the necessity exists for revision of Polish Design Codes, as well as the Codes presently in use in other countries (eg: Eurocodes EC3 and EC7) related to hydraulic engineering.

6. NOTES ON THE ENVIRONMENTAL LOADS ACTING ON BUILDINGS AND HYDRAULIC HEADWATER STRUCTURES

Types of loads

- Several Standards introduced in Poland for general use are related to the buildings. Three (3) of them elaborated in the Buildings Institute (ITB) as a most important contain climatological influences – from wind, snow and air temperature variations.
- Several other types of environmental loads are acting on the hydraulic headwater structures resulting from specific character climatic phenomena and other type of environmental loads conditions, viz.: wind actions, static pressures from ice, dynamic actions from floes, ice fields and waves, static water pressures and percolating ground water pressures.
- The exceptional environmental loads acting on land, as well as on sea are: earthquakes, and resulting tsunami waves on sea.

All above loads are related to hydraulic structures, and currently are not taken into consideration in design of buildings, and are not included in current civil engineer's handbooks.

The changes required to be introduced in Design Codes:

- The new revised versions of Design Standards (Eurocode EC7, etc.) should contain obligatory clauses related to the geomorphic and biologic regimes influence on general stability and strength of the hydraulic structures.
 - (a) In Eurocode 7, Dec. 1987, Preliminary draft produced by ISSMFE for the European Communities Geotechnics, Chapter 2, Clause 2.2.4.4., Subclause (4), page 10] the requirement was given for taking into account in static calculations the changes of water pressures resulting from the lack of care about cleaning the river channels from vegetation
 - (b) In the next edition of *Eurocode 7, Part 1, Geotechnical Design, General Rules, 4-th Version, 4 February 1993, Chapter 2, Clause 2.4.2..(8), page 11]* above requirement was given again. In next editions the problem has been neglected
 - (c) In the Standard EN 1997-1: 2002, (E), clause 2.4.6.1, (6) we can read :[*“Ground water- for limit states with severe consequences generally(ultimate limit states) design values represent the most unfavorable values that could occur during the design life time of the structure, With less severe consequences (generally serviceability limit state) most unfavorable values which could occur in normal conditions. In some cases extreme water pressures complying with clause 1.5..3.5 of EN- 1990-2002 may be treated as accidental actions*

(9).....changes of water pressures due to the growth or removal of vegetation. The standard recognizes “hydrogeological effects” instead of “hydrological effects”].

The Standard EN 1997-1: 2002 should be amended with the requirements resulting from the studies of geomorphic and biologic regimes

- (d) In the Standard EN 1997 – 2: we can read:
- Clause 3.2: “Design Investigations:**
- **Sub-clause (7): Maximum water levels observed during the investigations shall be recorded**
 - **Sub-clause (8): The extreme water levels of any water pressures which might influence the ground water pressures shall be established”,**
- Clause 3.3.6:** “Time effects”: should be taken into account in calculations of „transient” loads. The new innovative method is advised to be applied for determination the influence of river flow regimes changes on the channels flow parameters. (Naprawa, KRYNICA 2017, TKZ2017).
- (e) The proposed environmental classification of hydraulic headwater structures should be enclosed as **Annex to existing Standard Design Code for hydraulic headwater structures (hudraulic and structural part) - and titled.: „ Annex K: Method for recognition the water levels instability in erosive river channel”,** as well as additional particular technical conditions
- (f) Should be included also in the new versions of Eurocodes EC3 and EC7, basing on the conclusions resulting from the theory of geomorphic regime presented at Conferences KRYNICA 2017(polish version), TKZ2017(English version)

Additional safety conditions related to general stability of the hydraulic structures and strength of their individual structural members

- (g) The presently in force required conditions related to the general structure stability (on overturning and sliding) and related to foundation safety, new safety condition of type GEO (geology = subsoil= must be added, representing requirements resulting from the influences of geomorphic and biologic regimes changes:
- **Condition 1 of type “MORPHO ”H”:** eg.: influence of increased extremal high and low water levels, due to sediment transport (erosion and sedimentation); with 2 cases: case 1: at increasd W.L., and case 2 at decreased W.L.;
 - **Condition 2 of type “MORPHO ”Q”** eg.: influence of extremal , dischargesr discharges (with 2 cases: case 1: at increasd discharge, and case 2 at decreased discharges (due to sediment transport)
 - **Condition 3 of type “BIOH”:** eg.: influence of increased wetted perimeter roughnes DUE TO LACK OF CARE ABOUT GREEN PLANTATIONS BETWEEN LEVEES at extremal ROUGHNESS values with 2 cases: case 1: at increasd roughness coefficient , and case 2 at decreased roughness
 - **Condition 4 of type “BIOQ”:** eg.: influence of decreased discharge conveyance of the channel due wetted perimeter roughnes increase, and DUE TO LACK OF CARE ABOUT GREEN PLANTATIONS BETWEEN

LEVEES at extremal ROUGHNESS values with 2 cases: case 1: at increased roughness coefficient of the channel (decreased discharge capacity of the channel) , and case 2 at decreased roughness (increased channel dischrge capacity).

7. GENERAL TECHNICAL CONDITIONS FOR THE CANALIZATION OF LOWLAND RIVRS AND IMPROVEMENT OF INLAND NAVIGATION

1. The utilization of water power along the river should be completed by the construction of the series of barrages & dams located within the existing river channel & valley (in general along the actual flood inundation zone).
2. The afflux (U.S. Pool – D.S. Pool Elevation) at maximal flood flow of individual barrage should be limited to the values 10-100 cm (depending on local conditions and flood discharge) due to necessity of:
 - a. Limitation of pools & reservoirs influence on & along adjacent land to the minimum.
 - b. Creation of good conditions for gravity drainage of areas protected from permanent inundation by levees and dikes , allowing location of drains outlets d/s dams
 - c. Decreasing the possibility of soil piping & extent of water seepage under the head structures
 - d. Decreasing the expropriation limits and costs
 - e. Preservation as much as possible the existing flood flow regime at critical conditions, ensuring the possibility of river channel flushing & preservation within the created reservoirs, especially within the backwater upper zones of the reservoirs
3. The quantity of water diverted should be limited only for agricultural lands, municipal areas and industrial development infrastructure.
4. The number of derivation canals should be limited to the maximum extent due to
 - a. Bed soil conditions and possibility of large seepage (water losses must be evaluated),
 - b. Necessity of additional costs involved with concrete (or other type) canal linings, and thus
 - c. Necessity of elimination of troubles (& costs) related to poor soils behavior along the derivation canals
 - d. Necessity of decrease of the water losses resulting of additional evaporation from free water surface along canal.
5. The surfaces of U.S. pools at individual barrages should be limited to maximum possible extent, as the water losses for evaporation at hot climates are extremely large. This leads to acceptance the low head structures canalization system.
6. When low heads will be applied for individual dams & barrages along the river channel, more dense land communication system could be completed between both banks of the river, important for local communities and other purposes. Therefore at every head structure the road bridge crossing should be envisaged.

7. The proposed hydroelectric power stations should be equipped with horizontal axis reversible turbines, to allow the reverse water pumping and saving the additional energy output for peak hours consumption of electricity.
8. Application of reversible turbines with horizontal axes will decrease the depth of foundations pits for every HEPS (hydro-electric-power-stations) and will allow to decrease the construction costs and required time limitation.
9. In cases, where location of the structure is adjacent to the river confluence, the location of headworks U.S. of confluence mouth should be always accepted.
10. Due to variations in geological conditions for the whole cascade, every head structures should be located & designed basing on soil investigations, completed in conformity with the approved programme.
11. The reservoirs & diversion canals (if any) should be located on barren and un-habited lands.
12. In case the diversions will be decided within the river channel the sufficient discharge should be maintained for channel stabilization, to maintain the critical velocity flows as long as possible.
13. Collisions with engineering infrastructure should be avoided to the maximum possible extent.
14. The hydrological study for the designed cascade should comprise the determination of dominant discharge (QD) for the channel along the river reach under consideration.
15. Basing on the dominant discharges, sediment study results and regime parameters of the river determined, the operating conditions for individual barrage (and hydroelectric station) should be fixed and operating rules for the cascade should be proposed and approved.
16. The general design criteria for individual barrage & power station should be elaborated and approved. The criteria should incorporate all findings resulting of studies performed. The main purpose of these works should be preservation of natural flood flow condition along the river channel by designing its stable profile and cross sections.
17. It should be emphasized the fact, that at the sediment laden water flows during floods the flow velocities (in average) should not be lower than minimum acceptable values, ensuring sediment transport. The minimum flow velocity thus should not be less than critical (V_{cr}) e.g. the free flow of the river should be maintained for discharges $Q_{flood} \geq QD$, thus ensuring flushing operation and the sediments transport along cascade.
18. When discharges (Q) will be within the limits $Q > QD$ the river should flow in sediment transport regime, e.g. no decrease of the flow velocity is altered by heading up the upper pools at the proposed headworks below its critical values ($V > V_{cr}$.)
19. The above given requirements call for wide spillways openings. The total opening widths of barrages (for flood flow conveyance) however should not be less than $0,6B$ (when B is the distance between the opposite banks of the river channel at flow $Q_{50\%}$).
20. The spillway sill crests elevations of the proposed barrages should be fixed at elevations depressed not less than 1,0 m below the low water profile in natural condition. The position of selected openings must ensure the bed load passage.
21. As the low water flow will be controlled by barrages pools, the erosion at downstream reaches of the channel (below the barrages) will not possess any negative effect on navigation e.g. the river canalization will have the beneficial effects on navigation condition during long lasting dry season (VI-IX)
22. As much possible the side protective dikes should be avoided.
23. The number of created depression areas to be drained by a drainage pumping stations, should be limited to minimum.
24. **SPECIAL ATTENTION** should be paid to structural features of the barrages to be contracted. Their flood conveyance works should be designed basing on **"RIVER FLOW IN STABLE REGIME CONCEPT"**. This calls for design of low level outlets and/or low sill elevated spillways to allow flashing practices of the river channel U.S. barrage (within the reservoir backwater zone).
25. The cascade operation during the year should be described taking into account seasonal weather conditions (summer, winter).
26. Effects of silt deposits deposition and siltation processes should be specified.
27. Life of Project must be analyzed and determined.
28. Due to the above statements evaluation of economic effects of the proposed cascade on the energy production are to be verified. The practical annual value of energy should be specified.
29. The practical energy production period may be limited to the time periods pertinent to normal water flow (between floods and winter seasons). However this will decrease the total energy production & economic efficiency of the works.
30. The **PROJECT LIFE STUDY** should be based on long sediment study. The study should cover not less than fifty (50) years period. Special Program for sediments studies should be elaborated for selected stations operated. Otherwise the conclusions achieved and structures constructed may fail its function. Environmental classification of hydraulic headwater structures should be obligatory taken into consideration as the base for the proposed special sediment studies. [Naprawa, KRYNICA2017, TKZ2017].

8. GENERAL TECHNICAL CONDITIONS FOR SAFE OPERATION AND UPSTREAM POOL CONTROL AT HEADWATER HYDRAULIC STRUCTURES (dams, barrages, weir & regulators).

1. The change of flow regime in the rivers due to construction of hydraulic headwater structures may cause the elimination of sediment transport and sediment retention in the reservoir.
2. Continuous sediment movement observed in natural flow conditions is stopped after construction of the structure.
3. The processes detrimental to the safe operation of the headwater hydraulic structures should be eliminated by

- the proper discharge control by operation with the installed movable gates.
4. The excessive free tractive forces acting during flood on river bed & banks can be decreased to the safe values by increasing the elevation of U.S. Pool and reducing the bed flow velocity below critical values.
 5. The deposited sediments upstream the structure should be seasonably removed by flushing method. For this purpose the permanent U.S. water pool level should be lowered to induce the bed velocities increase above the critical values.
 6. The structures which are unable for deposits flushing practices should be reconstructed and remodeled
 7. After every flood the report should be elaborated on the actual geomorphic regime of the river (or stream).

- a. To allow the sediment control along the upstream approach navigation canal to the navigation upper head lock area, as well as to the downstream canal, the navigation lock design criteria should ensure the flushing operations, effected also through the navigation lock chamber. Thus the U.S.&D.S. approach navigation canals and lock chamber will be kept free of sediments due to utilization the tractive force energy of flushing discharges [Naprawa, 2012].
- b. To allow the seasonal flushing of these areas, the navigation lock structural solutions (elevations) should be adjusted to the flood flows through the lock chamber.
- c. The lock's upper head sill should be therefore designed respectively at the lower , thus the "flow in regime" will be possible.

The guides for elaboration the geomorphic reports are enclosed.

9. GUIDES FOR ELABORATION OF THE STREAM GEOMORPHIC REPORT

1. General

The Stream Geomorphic Report elaborated for the river channel allow to formulate the general guides on the following questions to be utilized for formulation the design criteria for canalization of the river channel:

- a. Vertical position of river bed along inflow and outflow channels to the outlets and spillways, as well as the position of low level spillway sill crest elevations at the dam -should be adjusted to low floods flow conditions at dominant discharges (Q50%).
- b. The "regime flow condition" of the river across the reservoir area at lowered upstream POOL. W.L. should be based on the results of evaluations performed in geomorphic report.
- c. Flushing practices minimizing the reservoir sedimentation process should be supported by the study. As is known from the practice [Wei Yonghui 1986, Naprawa 1986, 2004, 2010, 2011, 2012] the effectiveness of flushing practices is very high (60-70%).
- d. The application of seasonal systematic flushing practices described above will decrease the maintenance costs of the planned navigation waterway, and
- e. Will extend the reservoir volume life,
- f. Simultaneously the inexorable biochemical processes will be eliminated, or minimized.
- g. Taking above into consideration, to avoid continuous contamination increase within the reservoir (worsening of stored water biochemical and physical properties), the water conveyance structures (outlets, spillway) should be design in a way, ensuring the flood flows passage along upstream reach of reservoir at water velocities close to critical values (at lowered U.S. Pool) [Naprawa 1986; Wei Yonhui 1986,; Chen Lei, 2008]
- h. The described above "regime operation condition" "g"- should be incorporated in design guides and official regulations.

3. Guiding remarks on the design principles for water conveyance structures at dams (outlets and spillways)

- a. The structural features and vertical position of the spillway sill should ensure the undisturbed flow of sediments (bed load and suspended sediments)
- b. The outlet conduits (or low elevated spillway sill) should ensure the complete emptying the reservoirs.

4. Final Conclusions and recommendations

- a. This Summary Report should contain the most important information and analyzes results of studies on the river regime flow changes resulting from the geomorphic, biologic and other recognized processes, observed along the river channel during a last century.
- b. The analyzes carried out for selected station should show the following;
 - ✓ The vertical changes of channel's wetted perimeter,
 - ✓ Flood water levels increase or decrease,
 - ✓ Actual structure and flood levees risk class.
 - ✓ Variations in flood water levels (with time)
 - ✓ Changes in flood water levels
 - ✓ Siltation processes along the river bank areas.
 - ✓ Changes (decrease, increase) in low water levels,
 - ✓ Prevailling erosion phenomena
 - ✓ Channel degradation extent
- c. The prognoses (scenarios) for future water levels after "T" years may be completed using following simple formula [Naprawa 1986, 2003, 2011]:

$$H_T = H \pm S_H \times T \quad (cm)$$

where: H_T – water level after T years (cm);

H - water level read from actual discharge curve (cm)

S_H - water level stability factor (cm/yr) determined from the plotted

diagrams

(+) denotes W.L. increase

(-) denotes W.L. decrease

T - planned operation time (of levee or structures) in years.

- d. The results of the completed analyses related to geomorphic and biologic transformations (along the

- River channel and its influence on the freeboards required by the actual regulations)
- e. Statement on the necessity for modifications to be introduced by the designers to the water levels read from the discharge curves usually supplied by the Hydrological Section. However, the proper procedure is, that **future hydrological parameters**
 - f. **(Q_T , H_T) values predicted for the whole operation period (T) of the investment should be elaborated by authorized designers in cooperation with the hydrologists and operation staff**,
 - g. The **Stability Factor Method** (or other accepted method) should be applied in practice, as proposed and described. The changes of flow regime in river channel of fluvial origin should be taken into account. The geomorphic analyses are important parts of Reports on Environmental Assessment and Management Plans for every project.
 - h. The International Levee Handbook (ILH) chapters should be utilized in preparation the report
 - i. Regular reports on river channel stability should be prepared every 5 years, as well as in case on emergency (on special cases).
 - j. More attention must be diverted to the high roughness of vegetations within levees inundated area. Its influence on discharge conveyance capacity decrease of the river channels should be emphasized.
 - k. Existing degraded river channels must be cleared from high plants, bushes, trees and macro-levelling (earth works) should be seasonally obligatory for execution.

The extra levee freeboard height should be always applied after study, against overtopping, if required [Naprawa,TKZ2017].

10. CONCLUSIONS FROM THE COMPLETED STUDY REPORTS ON STREAM GEOMORPHIC AND BIOLOGIC REGIMES

1. The processes recognized in rivers flowing in erosive soils channels are influencing the flow conditions in dangerous direction.
2. The geomorphic and biologic regimes are of most destructive character, seriously influencing the actual safety of the environment (infrastructure, people, flora and fauna). These two flow types regimes eg.: geomorphic and biologic, may change the elevations of water levels during the life of the project – and river channel discharge conveyance capacity may be altered, in negative or positive direction.
3. The water levels (W.L.) elevations increase are observed due to sedimentation processes and lack of care about green plantations, but decrease of the W.L. in case of erosion. Thus the discharge conveyance capacity of the channels may decrease or increase respectively, as the situation can occur.
4. Taking above into consideration, the water levels assumed presently (2018) by the designers must be corrected due to geomorphic and biologic regimes consequences, as described in above.

5. New methods for design must be approved and edited in form of legal governmental directives, based on new approaches to the problems, as regards following:
 - quantitative risk management identifying,
 - risk monitoring and control, and
 - risk response planning, all as described above.
6. Risk response guides against geomorphic and biologic regimes effects are strongly required to be elaborated and approved internationally for use by the Engineers responsible for hydraulic and static part of hydraulic headwater structures
7. The environmental classification proposed [Naprawa, 2012, 2017,2018] should be approved for general use in polish Standards, as well as in other international Standards (eg.: Eurokode EC7), basing on guides issued by the ISSMGE. Due to these proposals all related regulations and standards must be revised, amended and approved for practice, to introduce the effective methods for the floods control.

To the used presently technical conditions related to the strength and stability level of type “STR” (structure-foundation), another four hydrotechnical particular conditions must be added, viz.:

- ✓ **Condition 1 of type “MORPHO H”:** eg.: influence of increased extremal high and low water levels, due to sediment transport (erosion and sedimentation); with 2 cases: case 1: at increased W.L., and case 2 at decreased W.L.;
- ✓ **Condition 2 of type “MORPHO Q”** eg.: influence of extremal discharges (with 2 cases: case 1: at increased discharge, and case 2 at decreased discharges (due to sediment transport)
- ✓ **Condition 3 of type “BIO H”:** eg.: influence of increased wetted perimeter roughness DUE TO LACK OF CARE ABOUT GREEN PLANTATIONS BETWEEN LEVEES at extremal ROUGHNESS values with 2 cases, case 1: at increased roughness coefficient, and case 2 at decreased roughness
- ✓ **Condition 4 of type “BIO Q”:** eg.: influence of decreased discharge conveyance of the channel due to wetted perimeter roughness increase, and due to lack of care about green plantations between levees at extremal roughness values with 2 cases: case 1: at increased roughness coefficient of the channel (decreased discharge capacity of the channel), and case 2 at decreased roughness (increased channel discharge capacity).

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