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Technical Assistance for Revising and Complementing the Feasibility Study Regarding the Improvement of Navigation Conditions on the Romanian-Bulgarian Common Sector of the Danube and Complementary Studies

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TECHNICAL WORKSHOP

AFDJ / IAPPD / Halcrow Romania team

29 Aug 2018, Bucuresti

Technical Workshop (29 Aug'18)

- Revised options – Bechet / Corabia / Belene / Popina
- Design approach – morphological principles to option selection
- Design approach – river training structures / islands
- Design approach – bank stabilisation
- Options appraisal – modelling results
- MCA – multi-criteria (objective) analysis
- Adaptive management

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Short presentation – TECHNICAL WORKSHOP
DESIGN APPROACH – BANK STABILISATION

29 Aug 2018, Bucuresti

Overview of principles used to identify planform and location of options and detailed works at critical sites

- Sinuous channels: reasons to adopt
- Morphological approach delineating planform
- Planning and design principles to develop options

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Professor Thorne: overall summary of Lower River Danube morphology

- Lower Danube displays planform elements that are straight, meandering, braided and anastomosed patterns.
- Navigation problems would be expected in straight reaches due to lack of the large-scale, coherent, secondary flows necessary to scour and maintain a clear thalweg
- Consider re-aligning straight reaches for the navigation fairway and/or installing hydraulic structures that 'work with natural processes' to generate flow and create thalweg curvature
- All frictional fluid tends to follow a sinuous path. Crossings between consecutive curves are spaced at intervals of 6 and 7 times river width. Flows in the lower Danube are no exception and any plans to train the river should recognise this.
- Most of the critical sites are characterised by sub-reaches with flows that divide around medial bars or islands ie anastomosed planforms with sinuous anabranches

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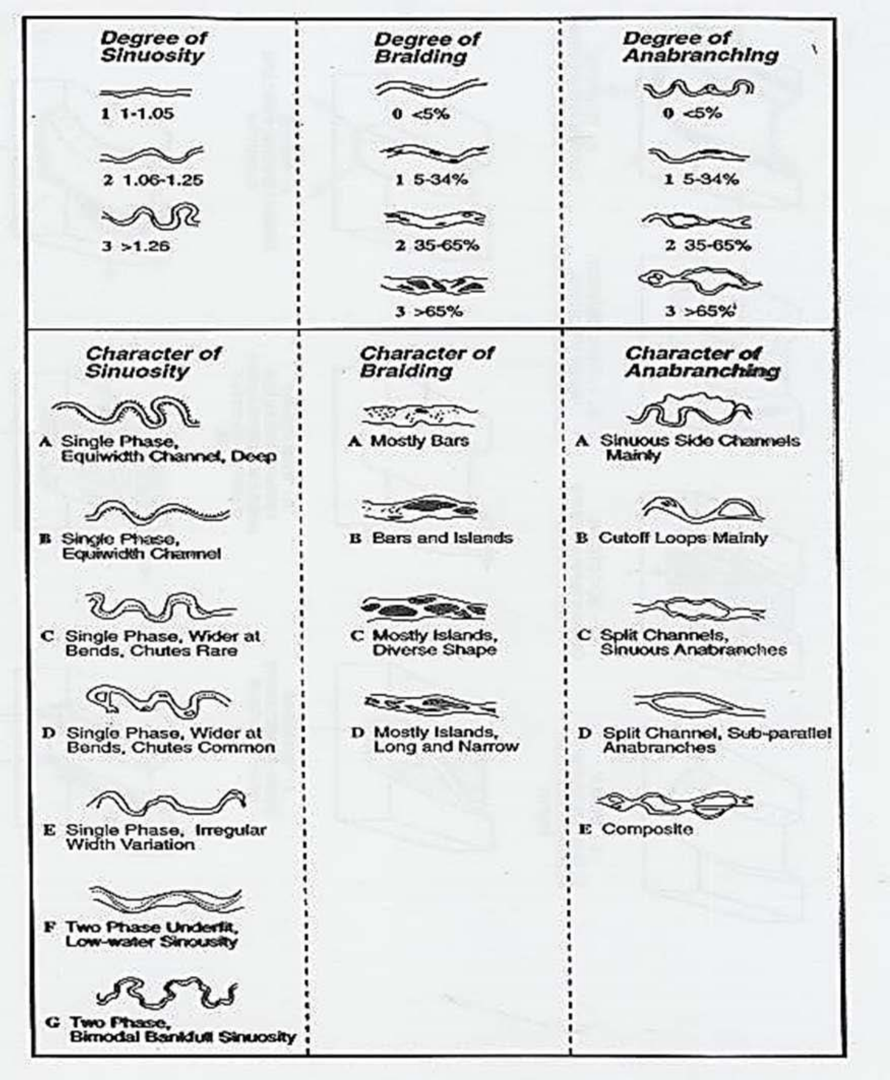

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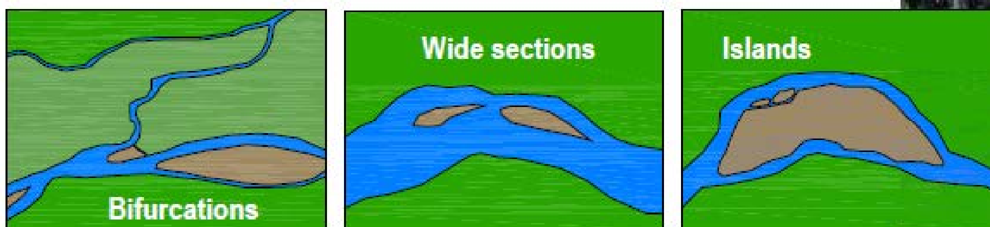
Lower Danube

Hydromorphological situation

Originally partially anastomosing morphology, sandbed river

Actual situation:



Side / bank erosion

Island development

Number of islands increased from 93 (1934) to 135 (1992)

Bondar & Teodor, 2008

Habersack et al., 2010

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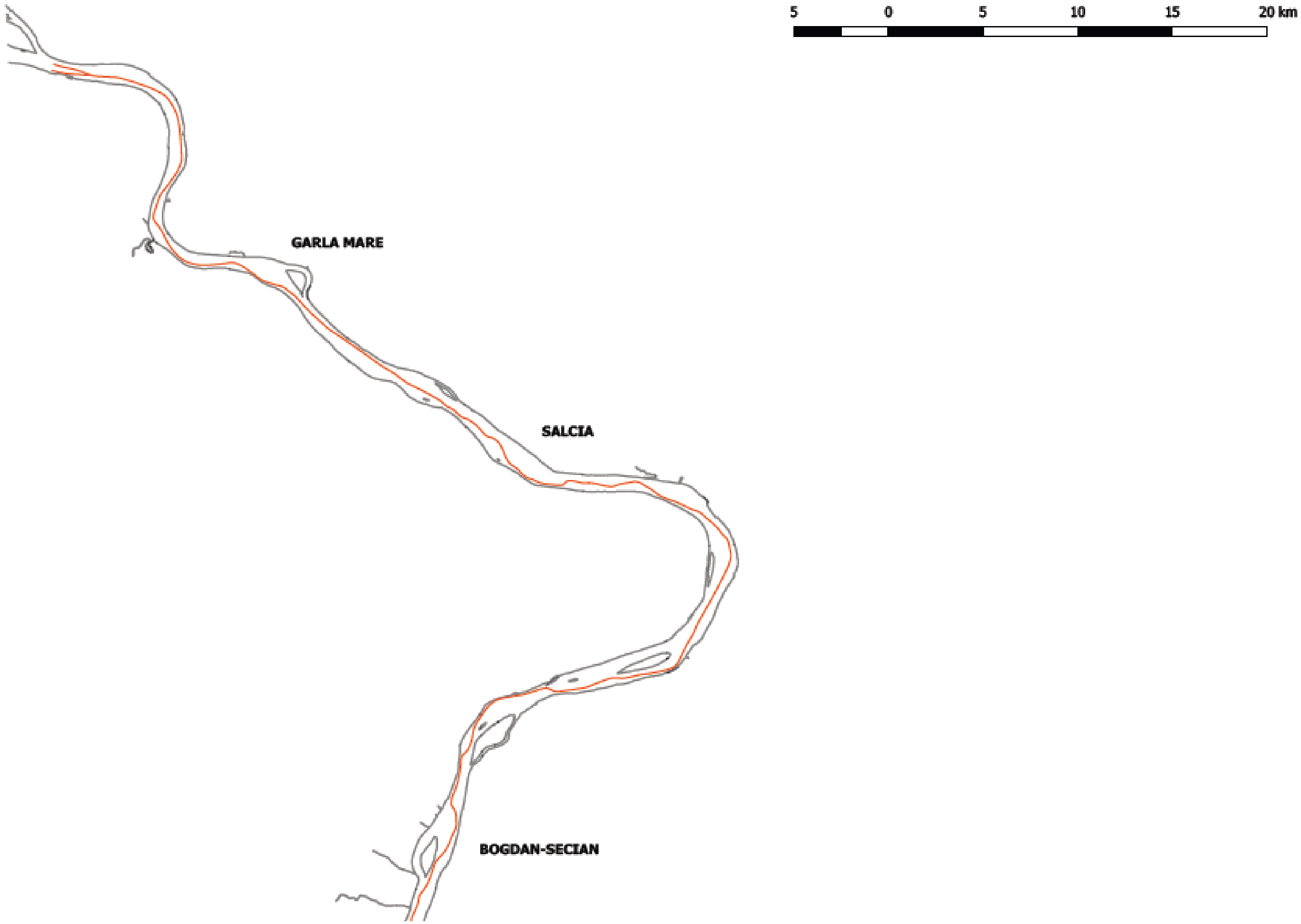

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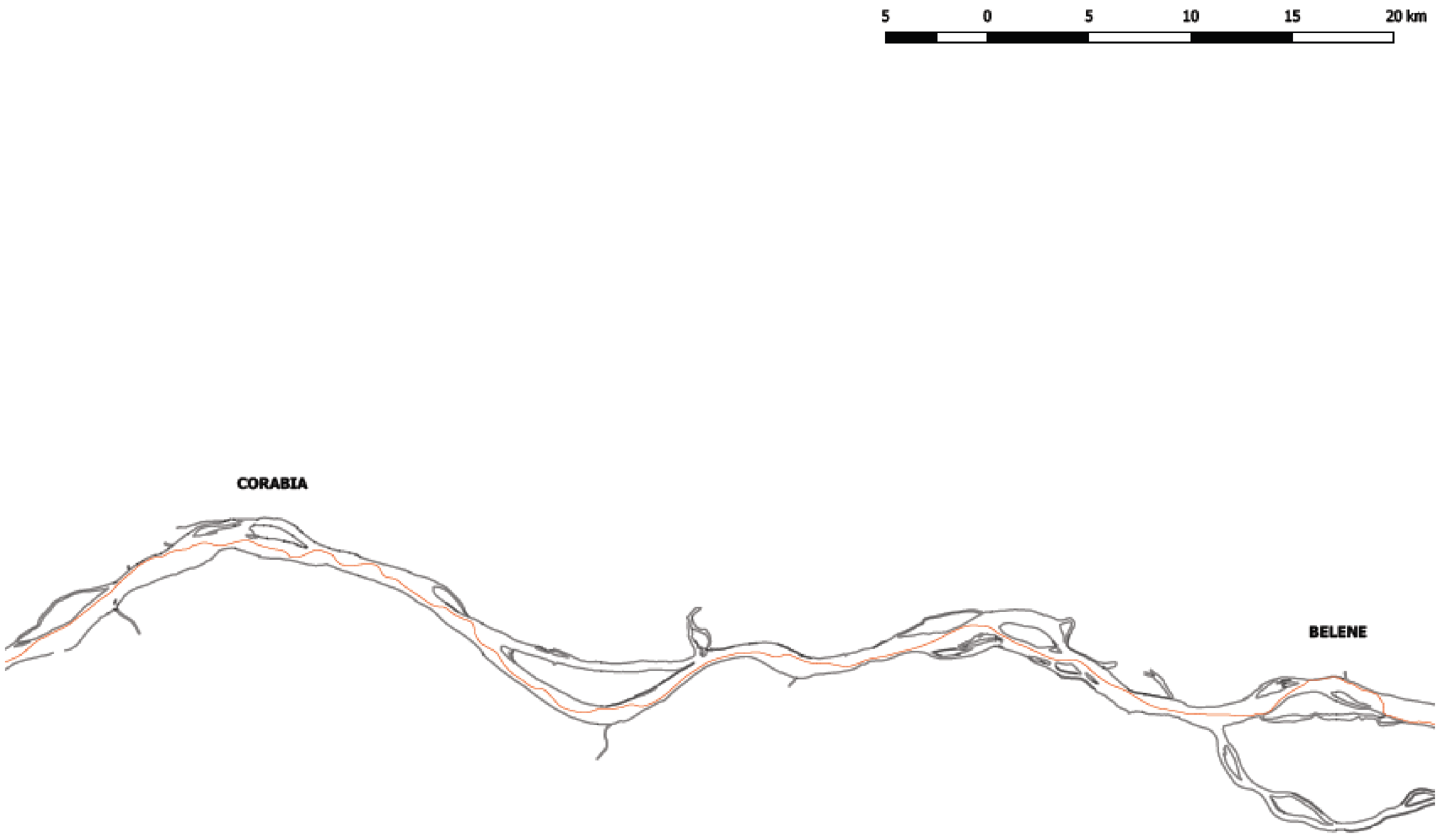

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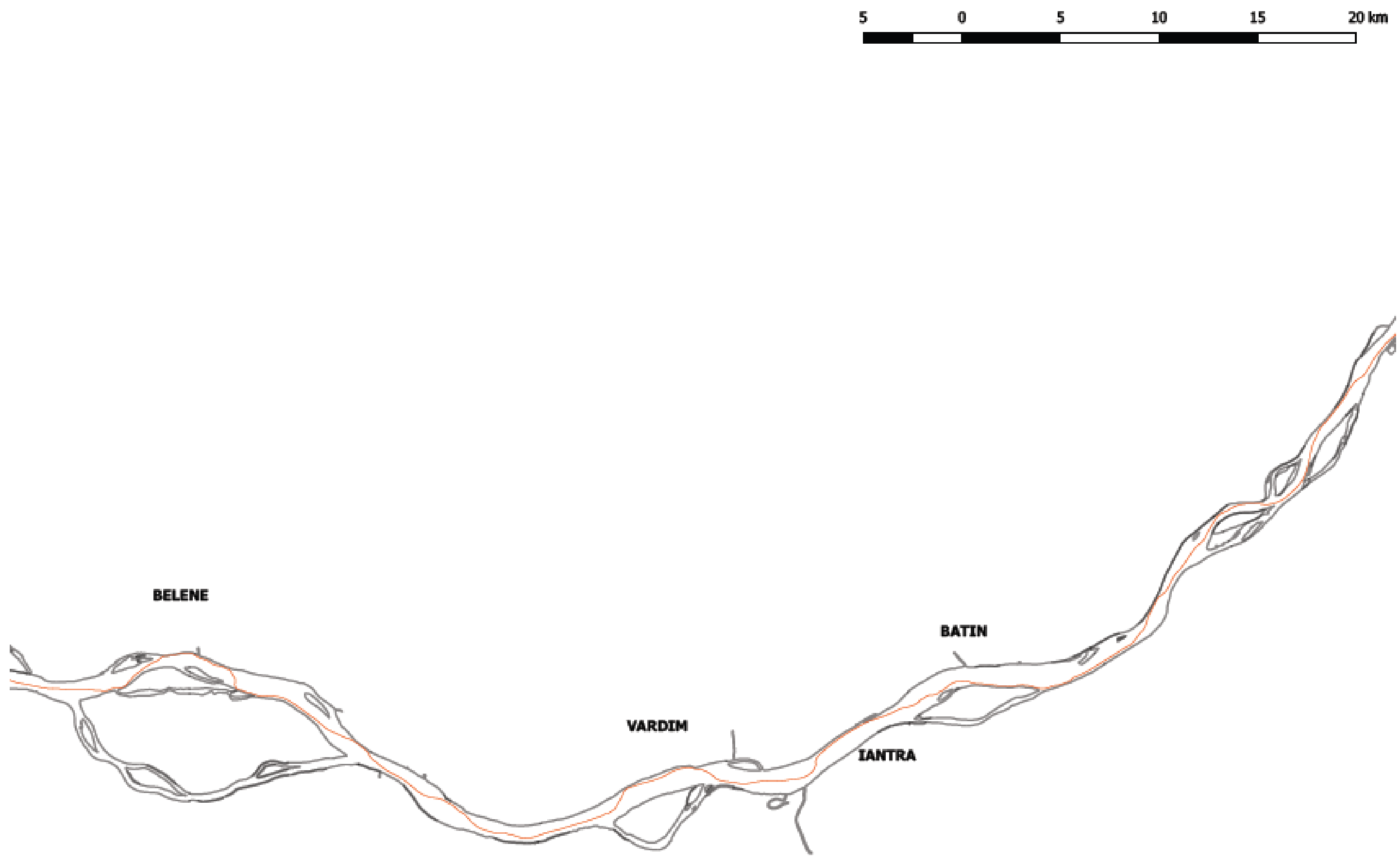

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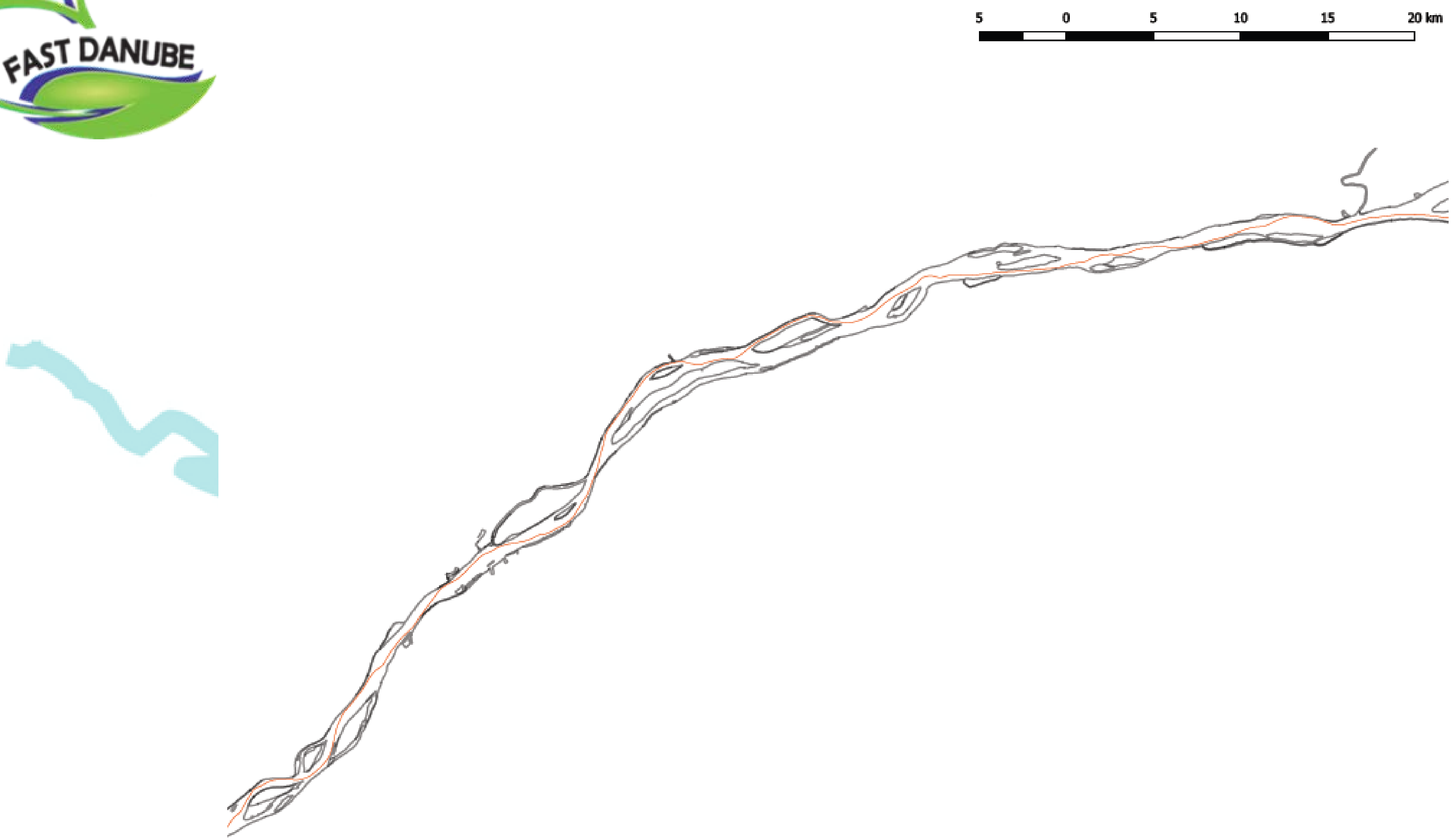

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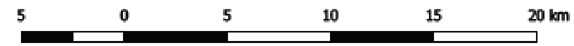

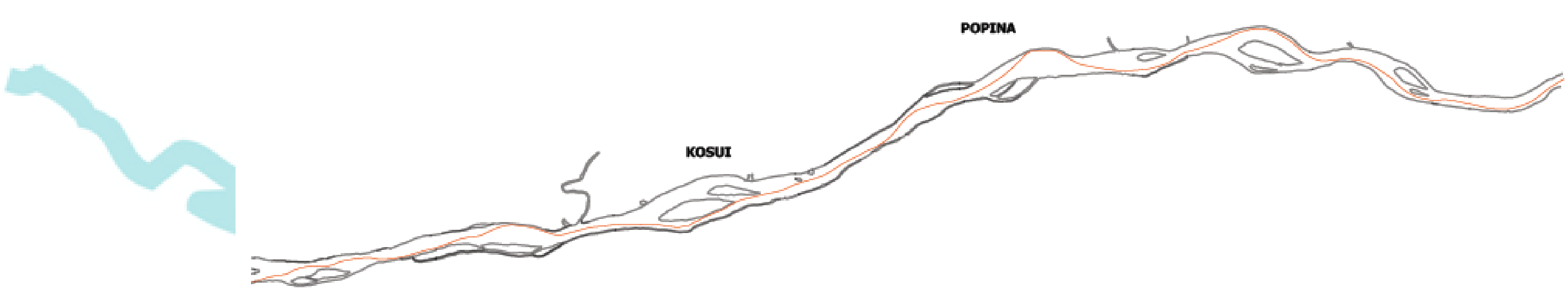

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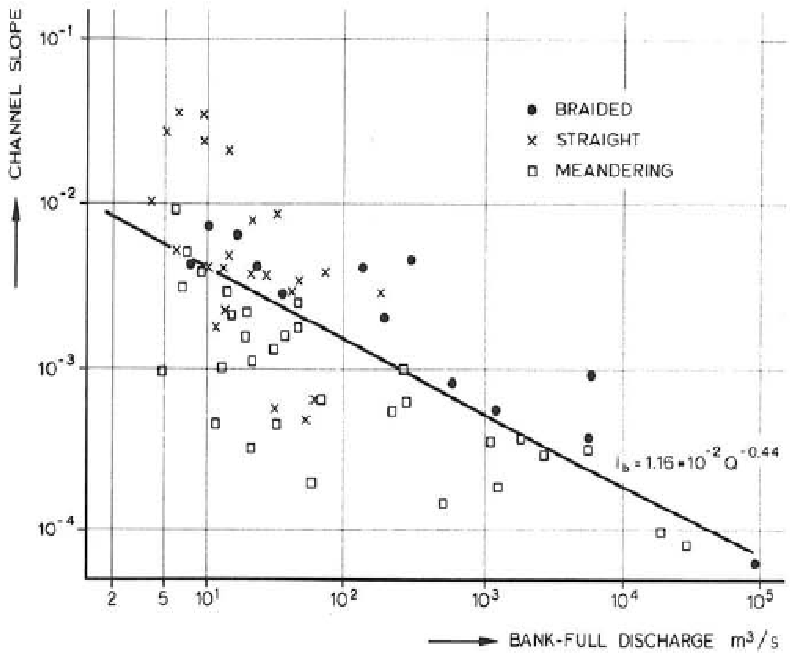
Fig. 2/4.3 Channel pattern (after Leopold and Wolman, 1957)



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- To generalise the Danube can be as narrow as 750m but is “normally” 900-1000m wide
- At its broadest usually coincides with double re-entrant banks eg Bechet, can be as broad as 1350m (and ~1800m with island(s)
- “Normal” bank width is ~ 1000m
- Generally (a) Garla Mare to Dobrina appears to have an amplitude of 4-5km and a frequency of ~15km (b) Dobrina to Batin an amplitude of 3-4km and also a frequency of ~ 15km; and (c) Batin to Popina an amplitude of 1-2km and a frequency of ~10-12km.

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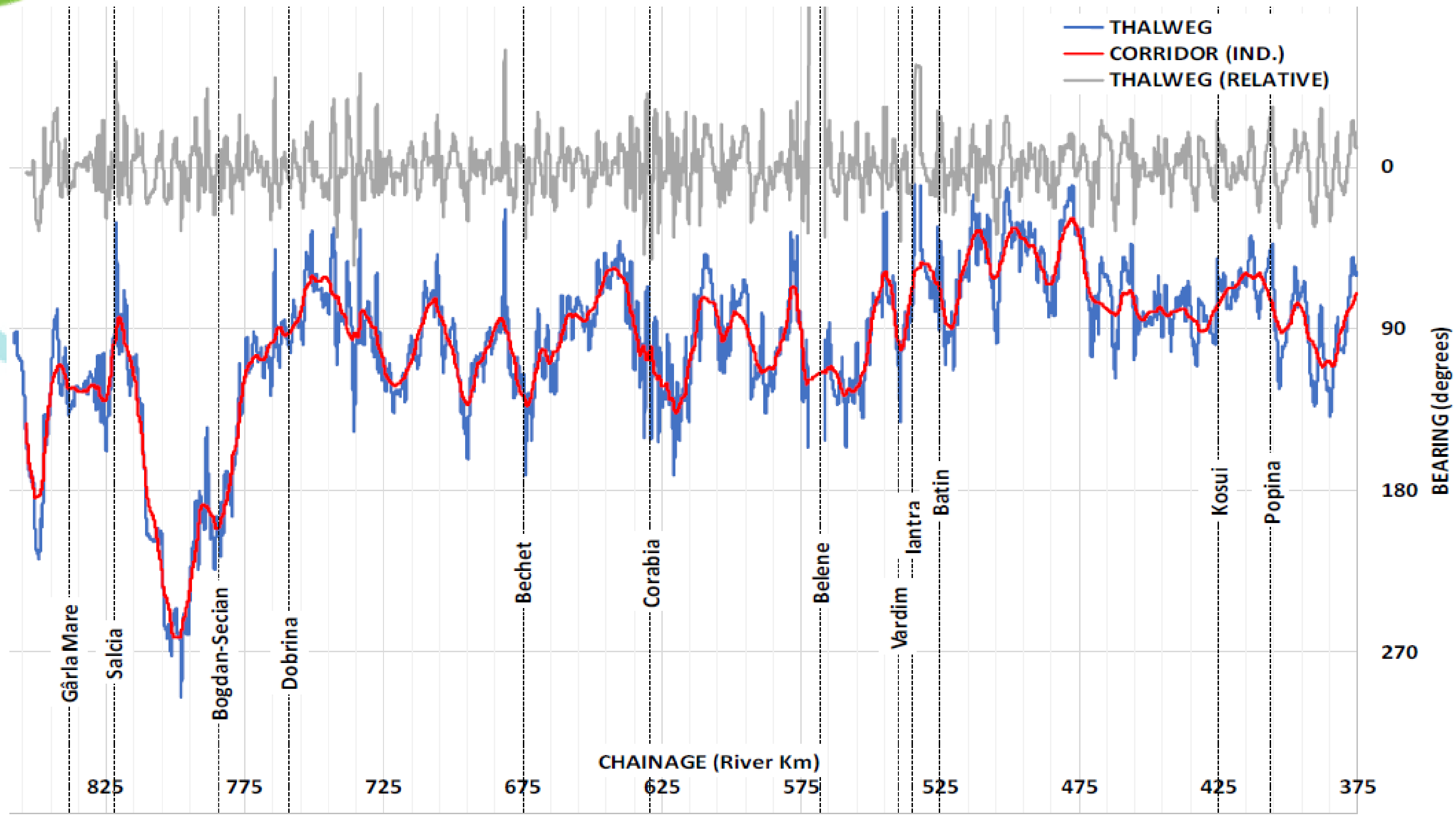

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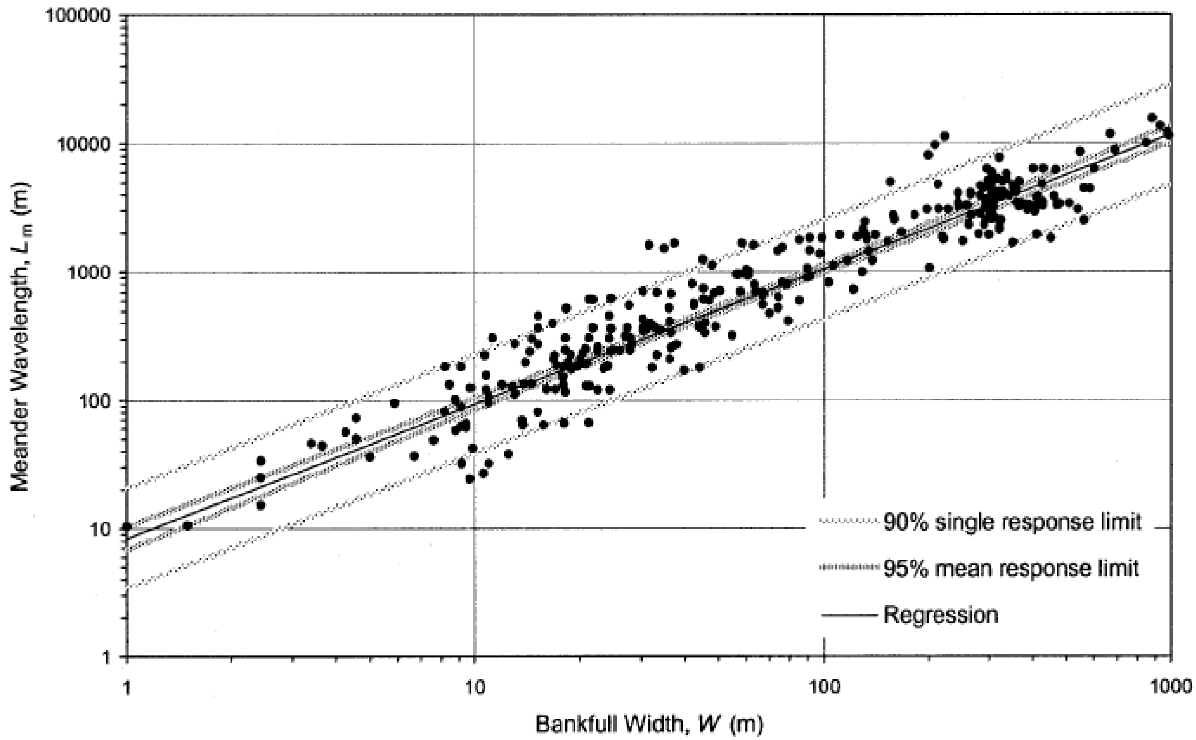
100000
10000
1000
100
10
1
Meander Wavelength, L_m (m)
1
10
100
1000
Bankfull Width, W (m)
90% single response limit
95% mean response limit
Regression

B. Winkley: Training the Lower Mississippi: studies and analysed 4 reaches in detail over decades (1930's to late 1970's) – actual hands-on lessons of sinuous versus straight channels for a very large sand river

- ***Ozark-Eutaw Reach (24km***): naturally very sinuous: cut-off and revetted into permanent sinuous alignment but less sinuous than natural: has had little or no navigation and maintenance problems
- ***Greenville reach (28km):*** naturally very sinuous : cut-off and straightened: locked into semi-straight channel: has had long history of navigation and maintenance problems
- ***Kentucky Bend-Mayersville reach (42km):*** naturally very sinuous: straightened with cut-offs: perpetually troublesome: realigned to sinuous path; now trouble free
- ***Baleshed-Ben Lomond reach (24km):*** historically straight: always troublesome: locked in to a straight reach: continues to be troublesome for navigation and maintenance

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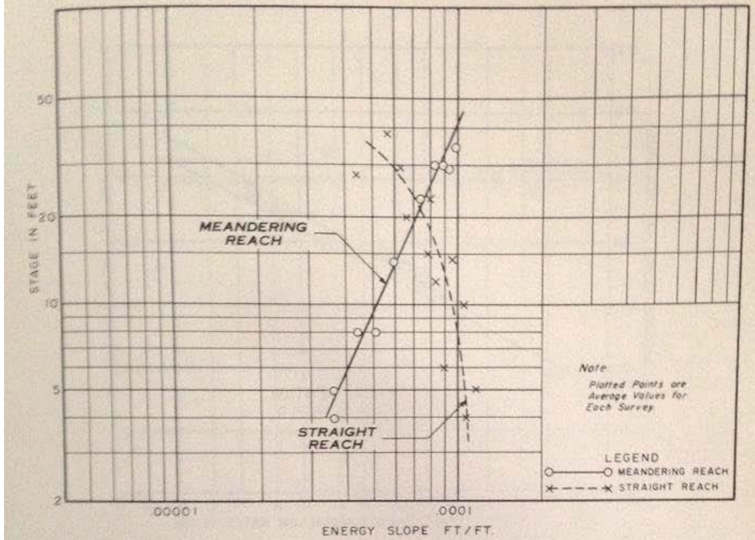

Fig. 24.4. Comparison of the variation of energy slope with stage height in meandering and straight reaches of the Lower Mississippi River

24.4.3 Slope

Figure 24.4 indicates the variation in the energy slope between a straight and a meandering reach. The meandering reach, because of its energy slope variations, does a better job of maintaining itself than a straight reach (1). Additionally, a sinuous river can adjust its slope by adjusting its path of flow; thus, it can more effectively balance the movement of sediments.

If a self-maintaining channel with better navigation depths and lower flood profile persists in reaches where a flatter low water slope and a steeper high water slope are present, as indicated by Anding (1), then a study of Fig. 24.5 shows some interesting comparisons of the four study reaches.

In Fig. 24.5, reach 1, Ozark–Eutaw (miles 580–565), shows a continued existence of flatter low water slopes and steeper high water slopes. This reach is a low maintenance, minimum construction reach. Figure 24.3 indicates a lower recent flood profile in this section of river than in the other reaches in this report, which could be partially the reaction from the cutoffs of the 1930s.

Reach 2, Greenville (miles 550–532), has very little variation in high and low slopes over the period of record. This consistent slope reach has experienced high construction and maintenance costs (see Tables 24.3, 24.4, and 24.5), possibly because the reach cannot balance its sediment load.

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Energy slope variation and sinuosity

- Sinuous channels have flatter energy slopes at low flows and higher energy slopes at high flow than straight channels.
- They are therefore better at maintaining themselves ie conveying high sediment loads at high flows.
- Below: (a) Ozark-Eutaw – sinuous channel, little maintenance (b) Kentucky Bend-Mayerville – 1966 to 69 when straight channel perpetually troublesome: realigned to sinuous later; trouble free

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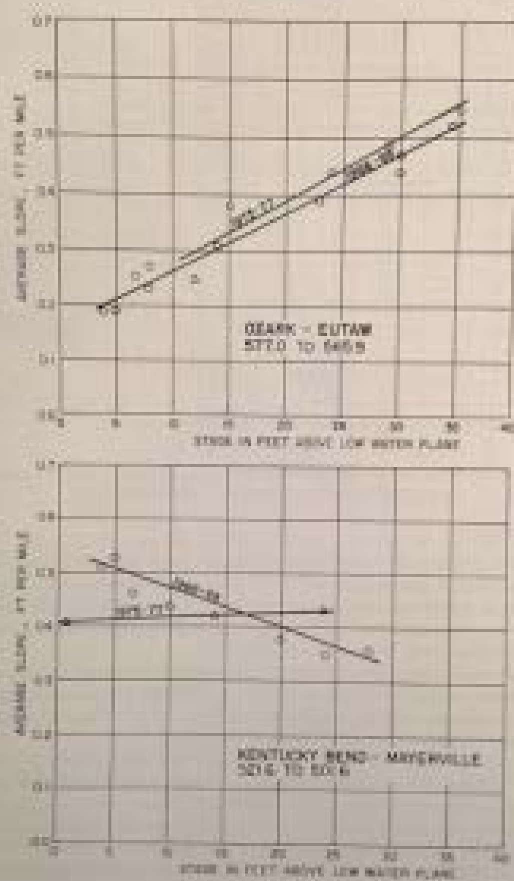
OZARK - EUTAW
STAGE IN FEET ABOVE LOW WATER PLANE
KENTUCKY BEND - MAYERSVILLE
STAGE IN FEET ABOVE LOW WATER PLANE

Investment in heavy engineering (groynes) and maintenance dredging dredging commitment: Mississipi: 1930s to late 1970s

- ***Ozark-Eutaw: sinuous channel***: very few groynes (~3000m): little or no dredging
- ***Greenville: semi-straight***: 20,000m groynes: high dredge commitment (60,000cum/km)
- ***Kentucky-Mayersfield: straight***: 10,000 m groynes: high dredge commitment (60,000cum/km): then put into sinuous alignment: dredge commitment eliminated
- ***Baleshed – Loch Lomond: straight:*** 18000m groynes: v. high dredge (90,000cum/km)

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Heavy engineering approach

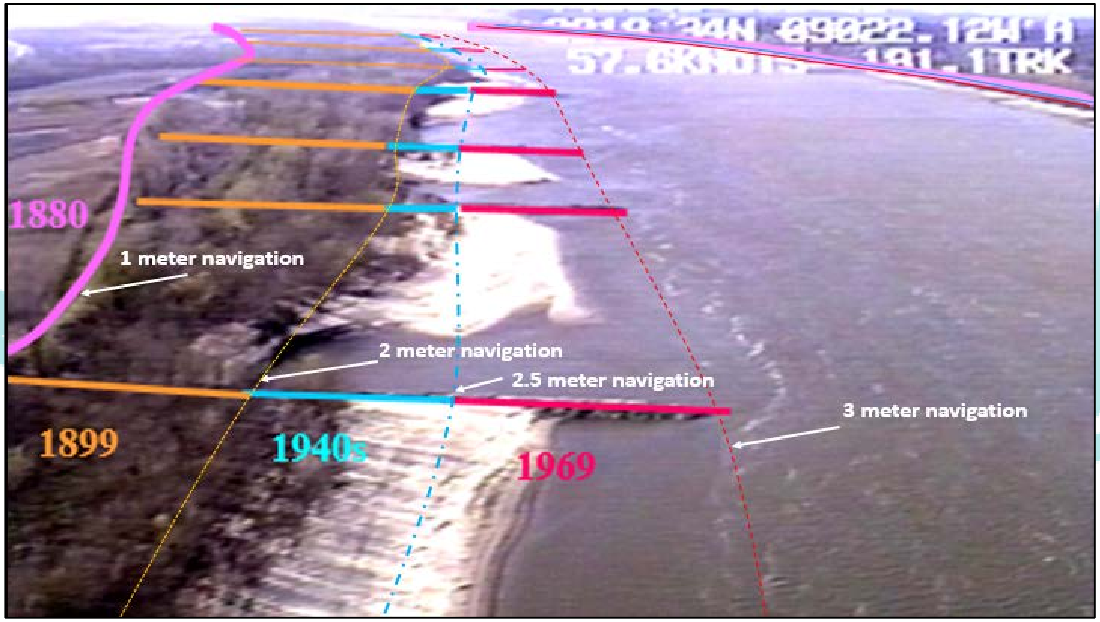

Illustration of the Various Stages of Navigation Design on the Mississippi River near St. Louis, Missouri USA – contraction to 55% of river width

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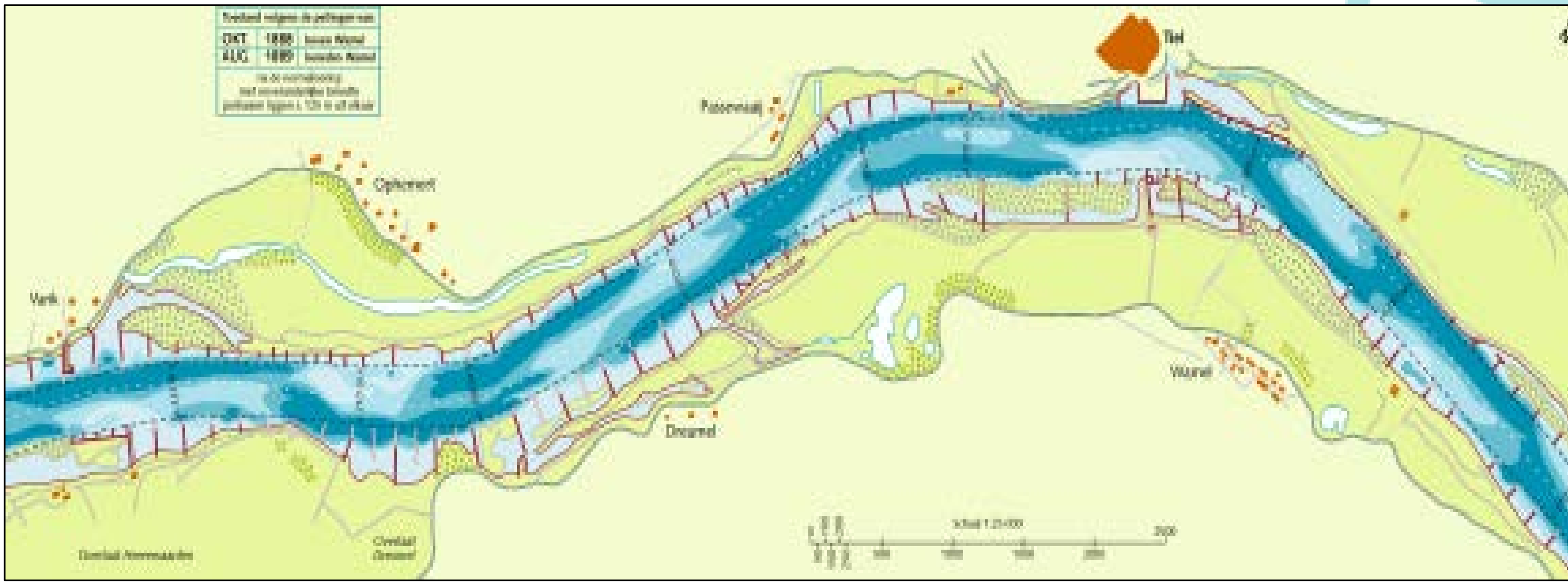
Heavy engineering: Waal River Netherlands: mid- to late 1800s: contraction of planform of river down to 50-60% of width



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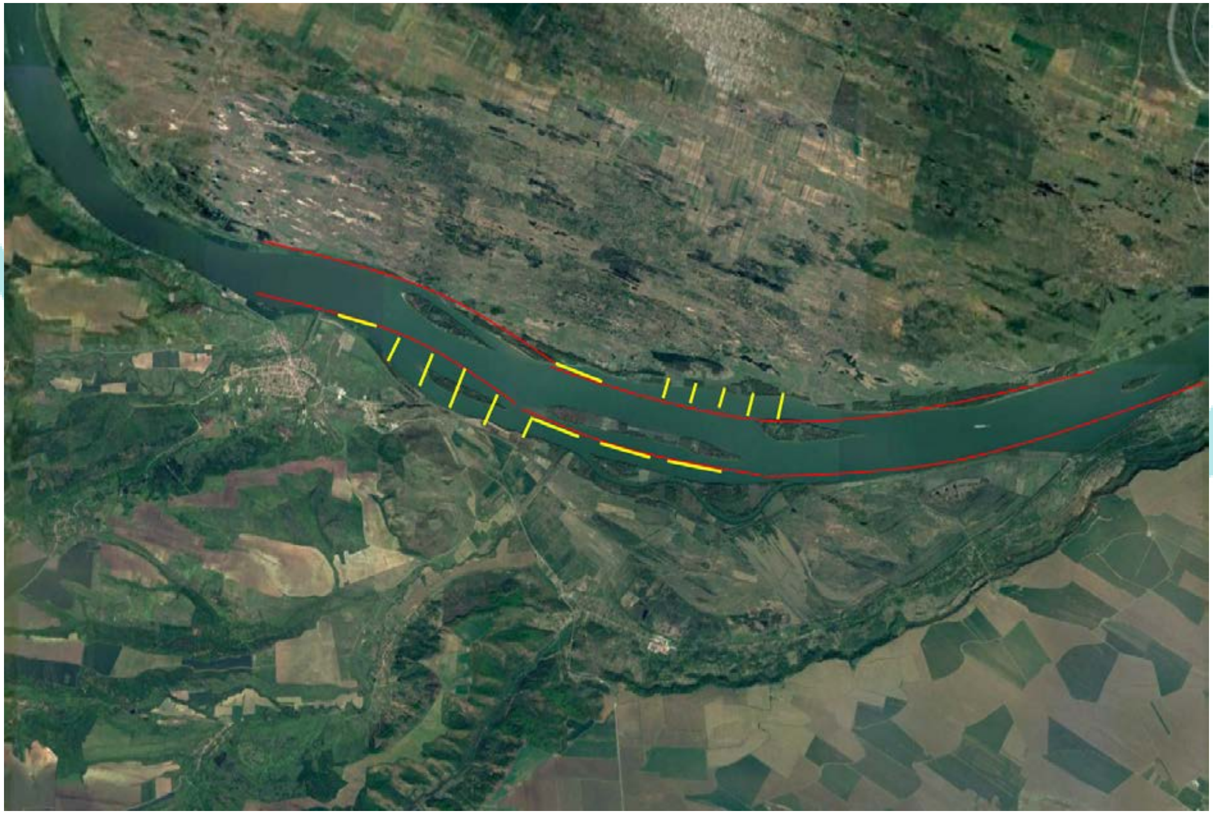
Typical USACE heavy engineering approach: contraction of river with lateral and perpendicular groynes to form sinuous contracted alignment



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Critical Locations: meanders lost, braiding occurs

- Erosion of islands or mainland banks is undesirable
- The width of the water surface increases which reduces the stream power per unit width
- Promotes shoaling, increasing the width to depth ratio thus increasing braiding tendencies and intensities - both are bad for navigation
- When bank erosion causes the channel to become overly wide compared to its stable, regime width, the pattern switches from sinuous/meandering to braided.
- Navigation suffers as braided channel are shallow with multiple shifting bars and shallow sub-channels.

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Channel evolution to form islands

- As the braided pattern evolves, some sub-channels (especially curved ones) incise a little into the braid plain, allowing the larger bars to transform into islands.
- Emergent islands are increasingly stabilised as they are colonized by vegetation, and the river pattern evolves from braided to anastomosed.
- Flow between the quasi-stable islands concentrates in 2 to 4 anabranches, each of which has its own planform pattern, which may be straight, meandering or braided.

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Planform for a stable sinuous channel

- The primary channel should pass along alternate sides of consecutive islands/medial sand bars.
- This is consistent with the natural tendency of the thalweg to cross from one side of the river to the other every 6 or 7 channel widths.
- That is the thalweg follows a sinuous pathway, with crossing spaced about 6 to 7 times the width and a meander wavelength of about 12 to 14 times the channel width.

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Promoting anabranch into stable sinuous channel

- In a weakly braided reach both the primary and secondary channels follow sinuous paths
- This creates a classic ‘figure of eight’ or ‘string of pearls’ planform
- Ideally the aim should be to promote flow in the primary channel; and then
- Have the navigation channel follow that sinuous alignment, while maintaining some base flow in the second channel for environmental purposes.

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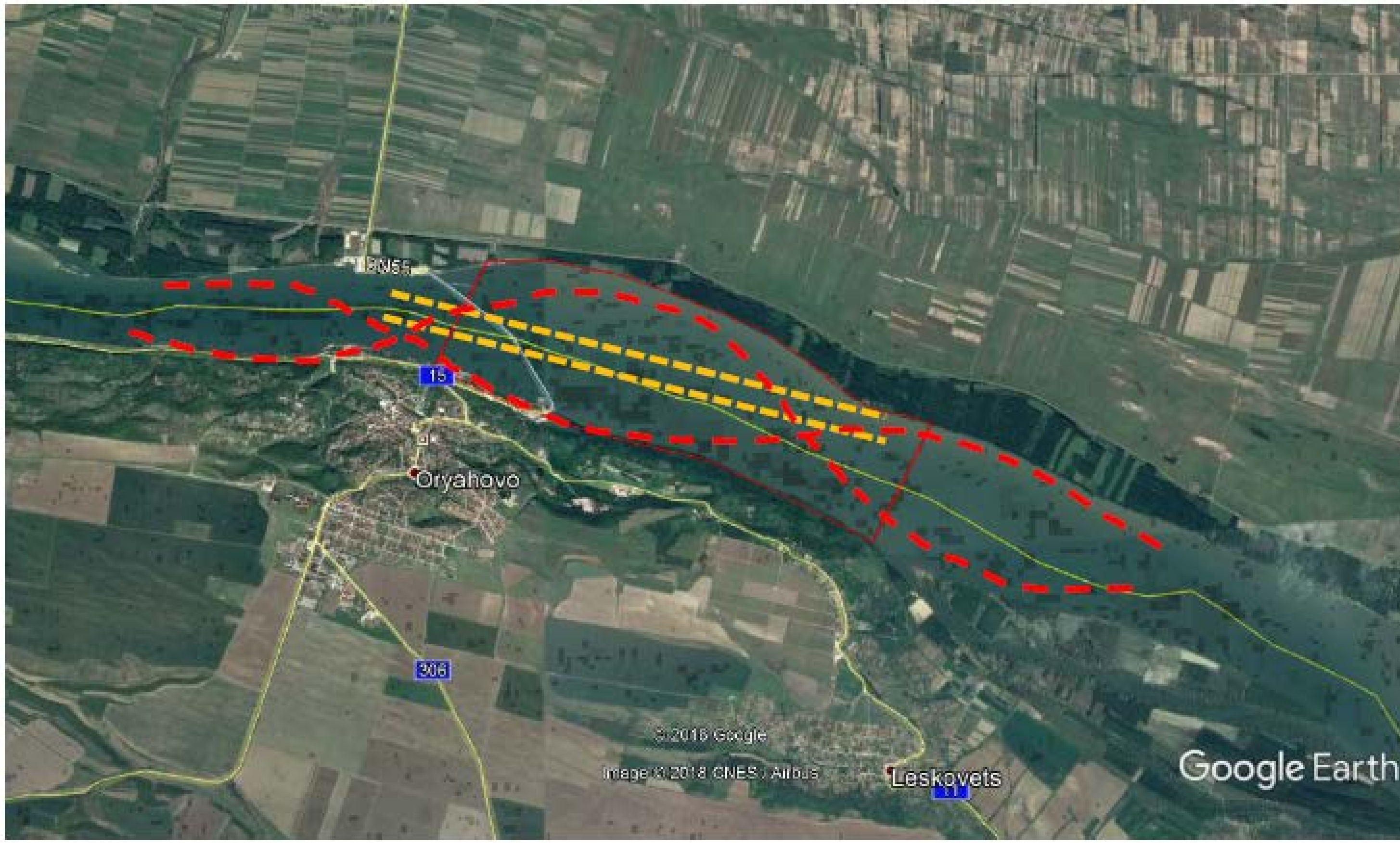

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SUMMARY: Three advantageous reasons to form a sinuous navigation channel:

- It generates strong secondary currents that help maintain a deep thalweg and hence sufficient navigation depths in the curved reaches of the primary channel between crossings
- It harmonises with the natural tendency of the thalweg to cross from one side of the river at intervals of about 6 or 7 channel widths
- It enhances sediment transport continuity at a wide range of discharges, including flood flows and so limits maintenance dredging needed to reducing bed elevations at crossings.

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Planning and design principles for navigation channels

Deciding on the planform and its alignment: morphological considerations

- Identify alternative anabranch sinuous channel alignments
- Match frequency and amplitude of channels to reach based parameters
- Match entry and exit of sinuous channel to upstream and downstream channel
- Identify alternative sinuous channel alignments with regard to bank planform
- Identify alternative sinuous channel alignments with regard to historic alignments
- Select alignment/anabranch which is less likely to braid: reasonable stream power
- Allow straights but avoid unduly long straight sections of channel

Deciding on the planform and its alignment: planning considerations

- Ensure planform consistent with navigation channel geometry requirements
- Avoid impacts or constraints upon existing infrastructure
- Avoid the locations of important environmental assets

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Identify options to create the required planform (groynes, chevrons, islands, bank stabilisation)

- Seek to avoid extensive heavy engineering: identify “minimum intervention” first stage works; plan for the need for further second stage adaptive works
- Allow back channels/minor anabranches to continue to function as fully as possible ie maintain or promote anastomosed planform
- Consider constructing and promoting the growth of islands to influence and train the river planform; locate on inside of navchannel bends; islands are part of natural river processes
- Consider constructing chevrons to influence and train the river planform; similar location to islands but principal function is to narrow river and concentrate flows in navchannel
- Consider groynes to divert/deflect river flows into sinuous alignment: typically located on outside of navchannel bend; bank location/connected
- Consider river bank stabilisation with range of green and grey types of measures: to reduce risks of river widening with potential braiding and subsequent loss of sinuosity
- Identify measures which might provide mitigation for environmental impacts, or even betterment eg ladder of pools for sturgeon in minor anabranches/back channels

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