A METHODOLOGY TO ASSIST IN GROINS DESIGN BASED ON NUMERICAL MODELLING

Angel N. Menéndez, Pablo E. García, Gustavo Salerno
angel.menendez@speedy.com.ar

INMAC S.A.
J. Ingenieros 3417, S.Isidro, Prov. Buenos Aires, Argentina
Phone/Fax (54 11) 4719 7217/18

Angel N. Menéndez, Ph.D. of The University of Iowa (USA), 1983, CPESC 2005, is a research engineer and consultant on hydraulic, hydrologic and water-related environmental problems. He works on flow, sediment, pollutant and heat dynamics. He is Head of the Computational Hydraulics Program at INA (National Institute for Water), Professor at the University of Buenos Aires and permanent consultant at INMAC. He is an expert in development and application of numerical models. He has numerous papers in international journals and has been head of a variety of research projects financed by governmental, private and international funds.

Gustavo Salerno, CPESC 2006, is a 1996 gold medallist in Engineering at the University of Buenos Aires, and obtained a Master of Business Administration degree from Austral University in 2001. Mr. Salerno has been very active in the field of erosion control in Argentina through his work as a constructor or advisor for many Argentine state agencies. He is now Vice President of INMAC S.A., where he has also acted as advisor for the application of erosion control products for many companies in Mexico, USA, China, Japan and Australia.

Pablo García, Engineer of the University of Buenos Aires, 2006, is a young professional that has already participated in many studies involving problems of erosion/sedimentation and pollutant transport involving numerical modeling. He has a fellowship at INA, and has contributed to some of INMAC research and development projects.

ABSTRACT

A methodology to assist in groins design is presented, which is based on the use of a 2D hydrodynamic/sedimentologic/morphologic model. It is applied to a stretch of the Pescado River, the main tributary of the Bermejo River, belonging to the Plata Basin, the second largest basin in South America. The particular stretch of Pescado River under study, in Argentina, is adjacent to an agrarian zone which has suffered bank erosion, and has now a series of groins designed, implemented and maintained by INMAC.

Two hydrodynamic models are implemented: a regional model embracing the adjacent island, and a nested local model concentrated in the threatened bank. The hydrodynamics drives a sedimentologic/morphologic model. Based on the obtained results, different indicators of the bank erosion vulnerability are built as spatial distributions (maps), namely, stream power, armour stability coefficient, and bottom erosion during the passage of a flood wave. It is concluded that only the latter acts as an appropriate indicator for the present problem.

The methodology is applied to optimize the performance of the present groins configuration, suggesting extensions for some of the groins. It is later used to produce an optimal configuration irrespective of present conditions, as a way to show the potential benefit of its application at the design stage.

Key words: groins design; numerical modeling; river erosion; bank erosion vulnerability indicators

1. INTRODUCTION

The use of groins to protect river banks from erosion remains essentially as an empirical technique. There exist some general rules regarding groins design (length, spacing, height, etc.). But not much use is given, in practice, to modern assessment techniques based on numerical models, which nowadays are relatively accessible, and could provide relevant information at the time of decision.

In this paper, a methodology to assist in groins design is presented, which is based on the use of a 2D hydrodynamic/sedimentologic/morphologic model. It is applied to a stretch of the Pescado River (Figure 1.1 and 1.2), the main tributary of the Bermejo River, belonging to the Plata Basin, the second largest basin in South America. The significance of the Bermejo River sub-basin lies in the fact that it is, by far, the main sediment producer of the Plata Basin, feeding the continuous advancement of the Paraná River Delta (with rates of 60 meters per year on the southern zone), and generating siltation in the dredged navigation channels of the Río de la Plata (the main grain exportation route for Argentina). The particular stretch of Pescado River under study is adjacent to an agrarian zone which has suffered bank erosion, and has now a series of 27 gavion groins designed, implemented and maintained by INMAC (Figures 1.3 and 1.4), which totalize 1,110 m in length.

Figure 1.1. Location of the study zone.

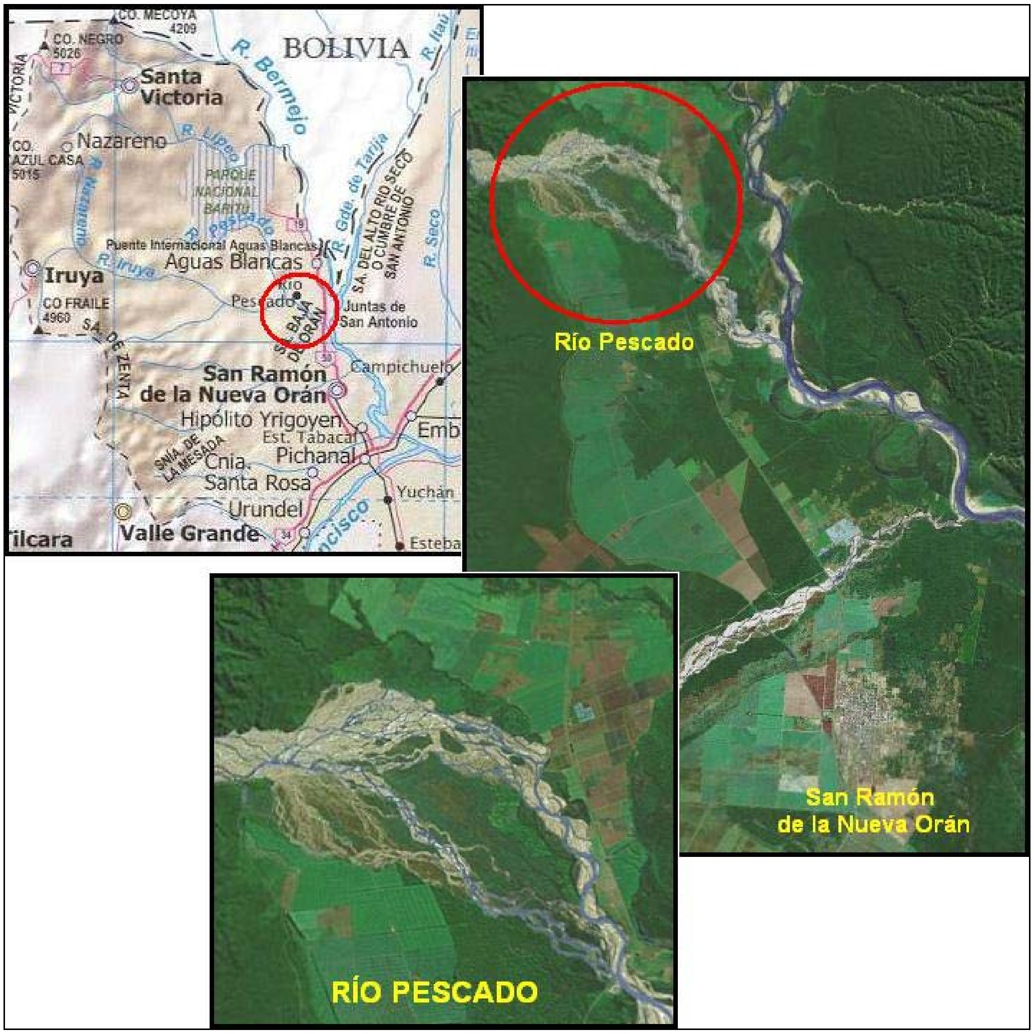


Figure 1.2. Detail of the location of Pescado River stretch

2. PESCADO RIVER

The Pescado River starts at Sierras Santa Victoria, at 4000 meters height. Its most significant tributary is Iruya River, which transports a heavy sediment load. The Pescado River is itself the main tributary of the Bermejo River, which divides Argentina from Bolivia. The area of the Pescado-Iruya basin is 5,000 km^2.

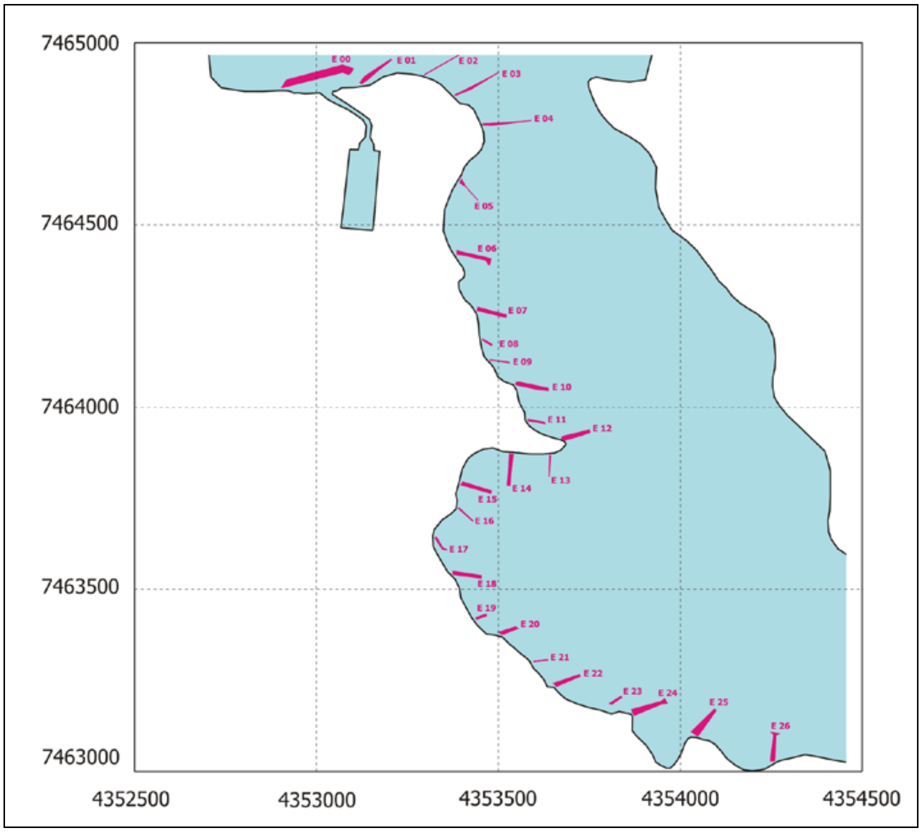


Figure 1.3. Location of groins

Figure 1.4. View of one groin at dry conditions and during the passage of a flood wave

At the study zone, the Pescado River has a slope which varies roughly from 10 to 6 m/km. The deposition of coarse sediment at the river bed, after floods, increases its height, so the active stream searches for secondary lateral channels in order to flow. Hence, during the next flood high velocities are generated close to the easily erodible banks.

Based on monthly averaged data at Colonia Colpana, a peak discharge analysis was performed, obtaining the peak return periods shown in Table 2.1. Further analysis on hourly data (provided by the company EVARSA) led to the estimation of a peak hourly discharge of 8,200 m^3/s associated to the 50-year return period flood. The corresponding flood duration was estimated as 1 hour.

Table 2.1. Peak monthly average discharge for different return periods.

Return period [years]	Discharge [m^3/seg]
2	1091
5	1630
10	1990
25	2444
50	2780

3. NUMERICAL MODELS

In view of the relatively large extension of the flood wave in comparison with the longitudinal dimension of the study zone, it is possible to describe the flow with a 2D-horizontal (i.e., vertically integrated) model. Software DOSDE, developed by one of the authors, was used (Menéndez 1990).

Due to the fact that, during high floods, in the study zone the flow divides into two branches, two hydrodynamic models were implemented: a ‘regional’ model embracing the whole island (providing then the partition of the discharge), and a ‘local’ model concentrated in the threatened bank (with boundary conditions provided by the regional model) (Figure 3.1).

Topographic data obtained from surveys made by INMAC were available to build the Digital Terrain Model for each hydrodynamic model. A grid of 20 x 20 m was used for the regional model (Figure 3.2.a), which was reduced to 5 x 5 m for the local model (Figure 3.2.b). Hydraulic resistance was parameterized with Manning roughness coefficient. A uniform value of 0.045 was used based on observation (Ven Te Chow 1959). The driving force is the river discharge, imposed at the upstream boundary. The water level must be given at the lower boundary, which then behaves as a conditioning to the flow. This water level is related to the discharge through a relationship built on measurements at Cuatro Cedros station, on the Pescado River.

The sedimentologic model is based on Meyer-Peter & Mueller bed load transport formula (Martín Vide, 2003). The morphologic model uses Exner equation to provide the evolution of the river bottom (Raudkivi, 1990). Both of them are incorporated within software DOSDE, operating interatively for each time step.

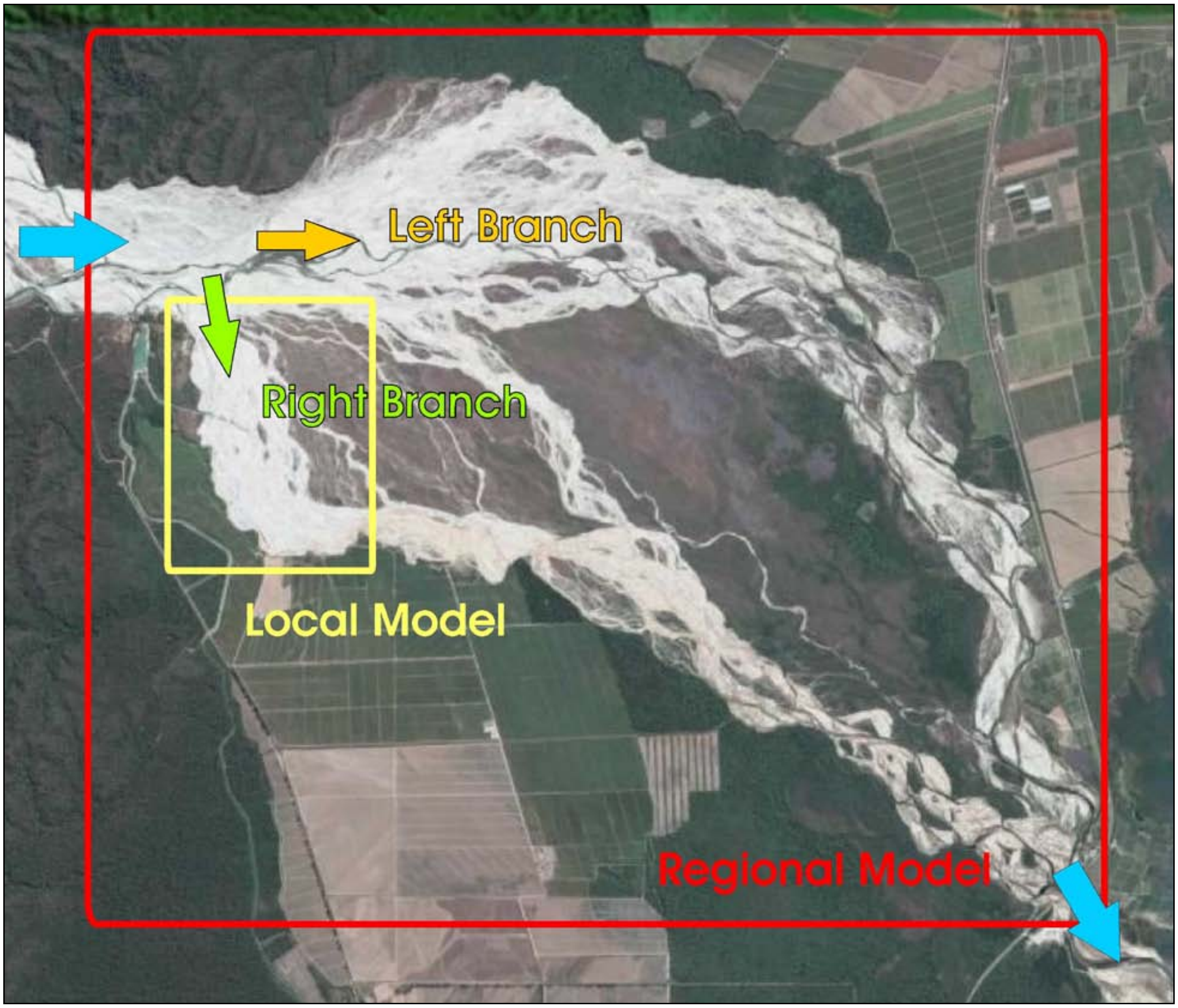
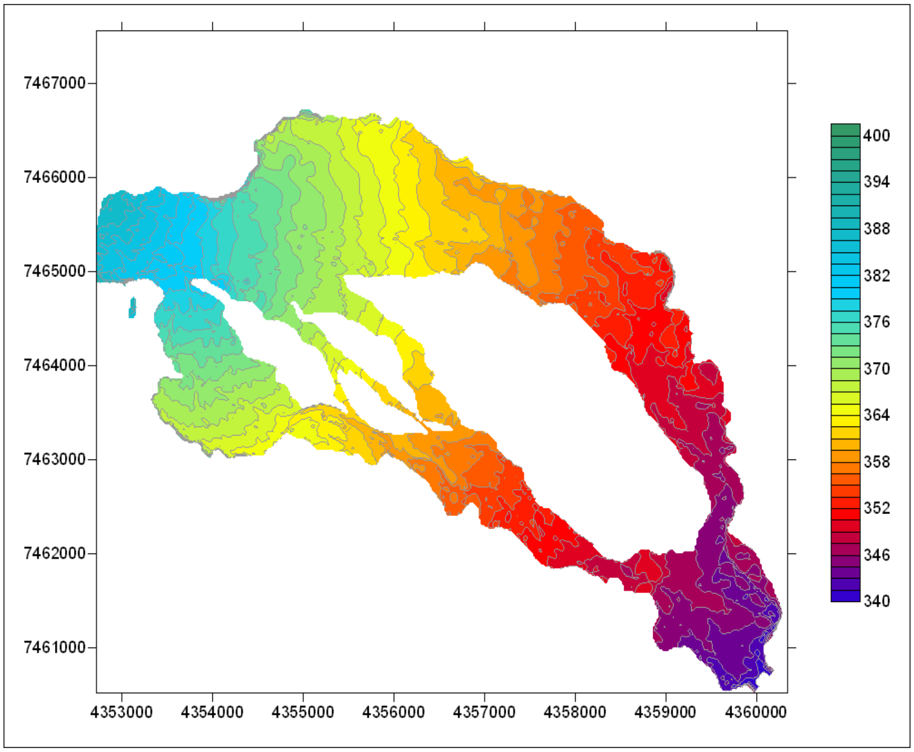


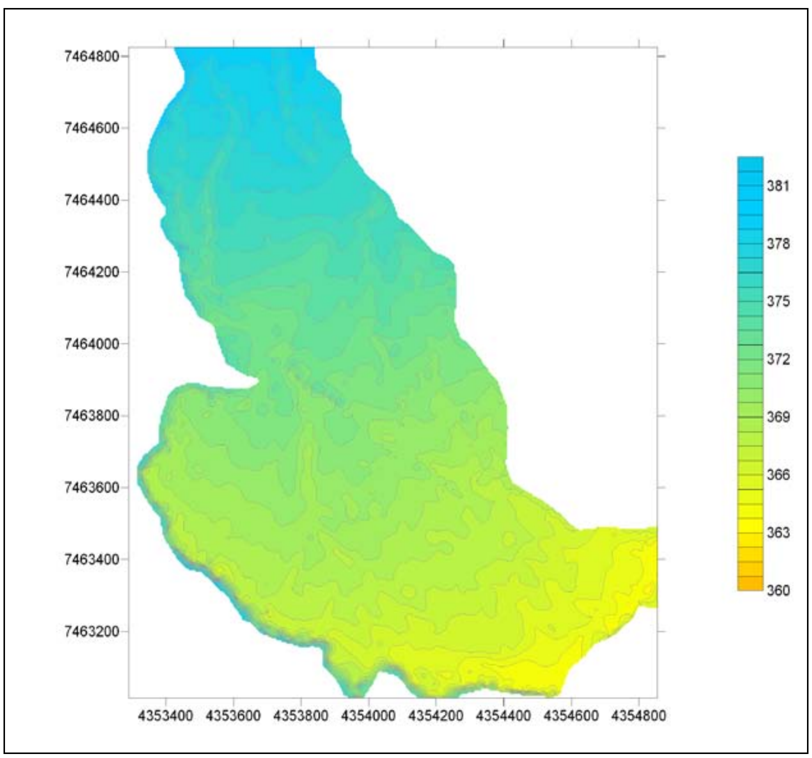
Figure 3.1. Representative diagrams of the hydrodynamics models.

4. INDICATOR OF BANK EROSION VULNERABILITY

From observations, it was concluded that bank failure is triggered by erosion of the near bank river bottom. Hence, different potential indicators of vulnerability were built based on the water current, in order to select the appropriate one, from the simplest towards the more complex ones.



a) Regional model.



b) Local model.

Figure 3.2. Digital Terrain Model (in meters) for the hydrodynamics models.

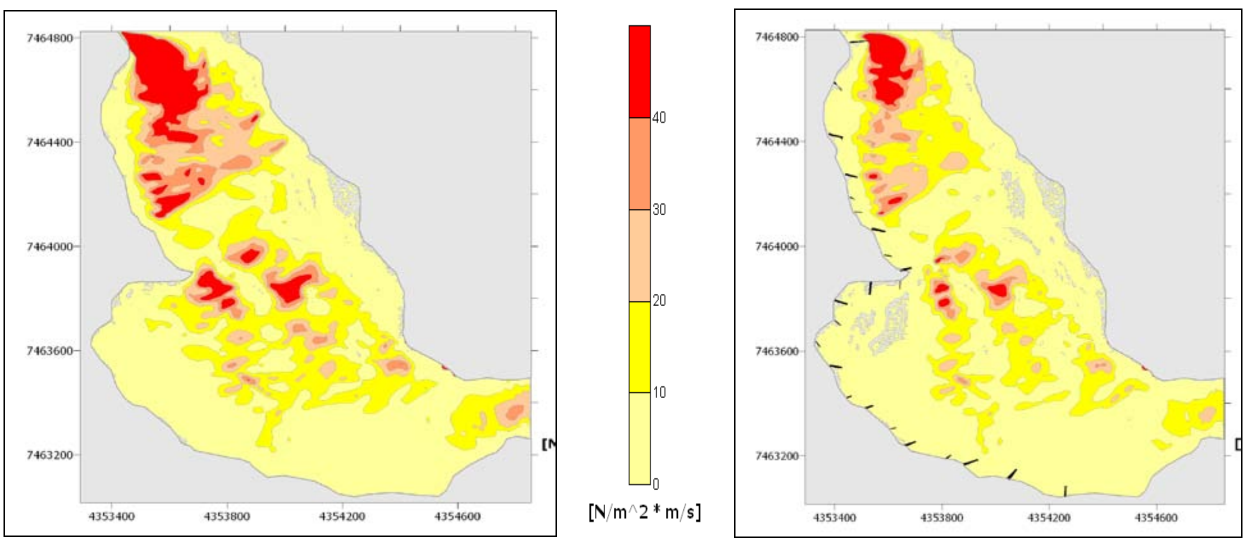
4.1 Stream Power

From the velocity field obtained with the hydrodynamic model, the spatial distribution of 'stream power' (the product of the velocity and the bottom shear stress) was obtained, as a first potential indicator of bank erosion vulnerability.

Figure 4.1 shows the stream power for the 10-year peak monthly-averaged discharge, for the cases with no groins and with the present groins configuration. It is observed that the presence of the groins manifests as a general decrease in stream power. This is associated to the fact that the discharge through this river branch diminishes due to the increased resistance. However, no changes are distinguished close to the banks, so this is not considered as an adequate indicator of bank erosion vulnerability for the problem under consideration.

4.2 Armour Stability Coefficient

In the second place, using the hydrodynamic field and available grain size distribution data, the spatial distribution of armouring probability (Gessler 1971) was calculated. Figure 4.2 shows the stability coefficient (values lower than 0.5 are considered as an indication of instability) for the peak hourly discharge of the 50-year flood, for the cases with no groins and with the present groins configuration. It is observed that, even without groins, the unstable zone is far from the banks, indicating that, in the near bank zone, conditions for armouring exist. From these results, it can be interpreted that the bottom erosion that develops during the armouring process is enough for producing bank failure. Hence, it is concluded that this is neither an appropriate indicator of bank erosion vulnerability for the present problem.

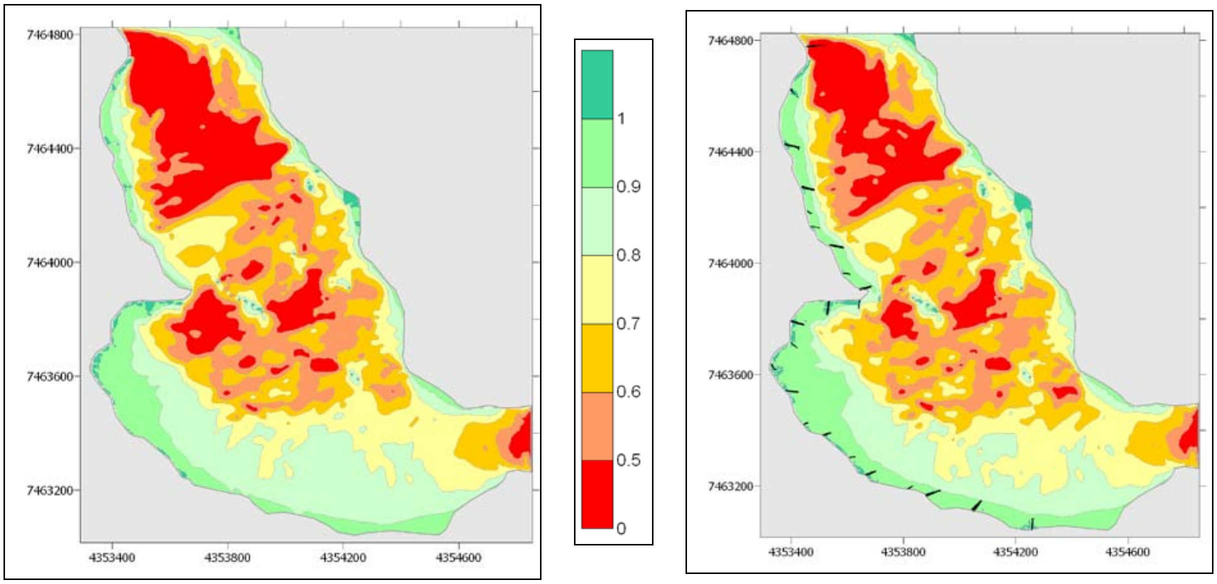


(a) No groins (b) Present groins configuration

Figure 4.1. Stream power distribution for the 10-year peak monthly-averaged discharge (2,000 m^3/s).

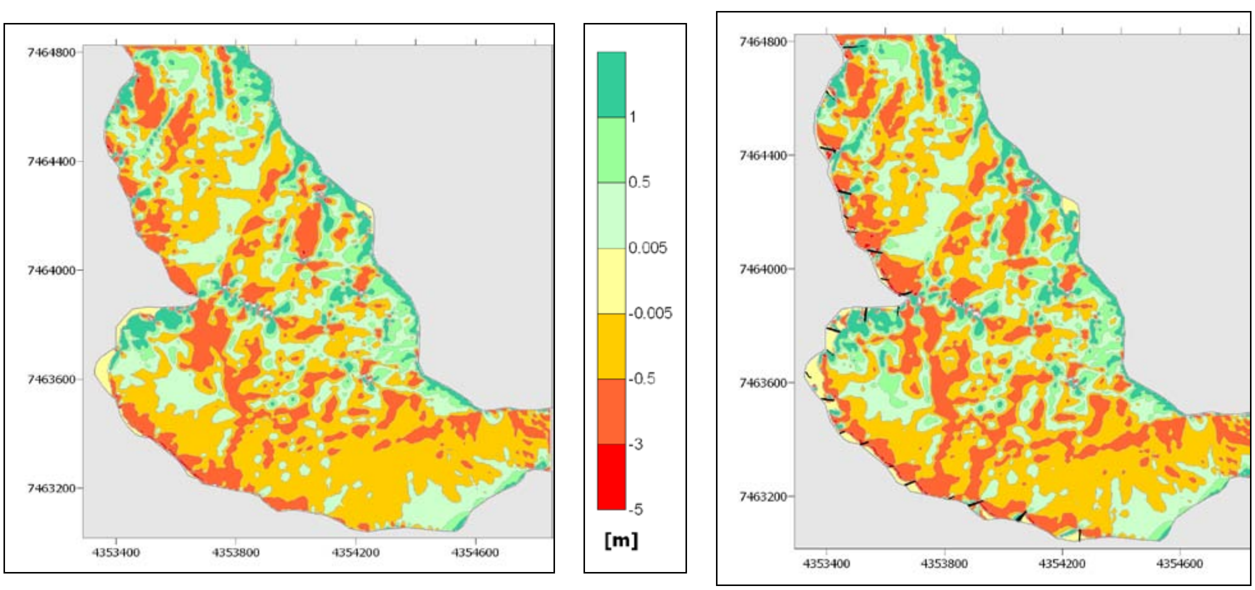
4.3 Bottom Erosion

The bottom erosion during the passage of the peak hourly discharge of the 50-year flood, considered as active for 1 hour, was calculated using the complete hydrodynamic/sedimentologic/morphologic model. The results are shown in Figure 4.3. It is observed that the model indicates significant bottom erosion in most of the bank zone for the case with no groins, which means that this magnitude constitutes an appropriate indicator of bank erosion vulnerability. The introduction of groins translates into the formation of shadow zones immediately downstream of each one of them, where bottom erosion (and, consequently, bank erosion) is then avoided. Note that in some zones the groins configuration is not effective to avoid erosion close to the bank. The model was then used to analyze strategies for improving the groins performance, as discussed in the following section.



(a) No groins (b) Present groins configuration

Figure 4.2. Armour Stability Coefficient distribution for the peak hourly discharge of the 50-year flood (8,200 m^3/s).



(a) No groins (b) Present groins configuration

Figure 4.3. Bottom level variation distribution after passage of the hourly peak of the 50-year flood (8,200 m^3/s) for 1 hour.

5. IMPROVEMENT OF GROINS PERFORMANCE

Two strategies were undertaken to improve the groins performance in relation to bank protection. In the first place, the present groins configuration was adopted as fixed, allowing only modifications in the extension of some of them – this is named as the 'conditioned strategy', as it starts from the present situation. In the second place, variations in the groins configuration (location and inclination) were allowed – this is named as the 'rational strategy', as it looks for optimization using a model as an assistant starting from scratch, independently of the actual situation.

5.1 Conditioned Strategy

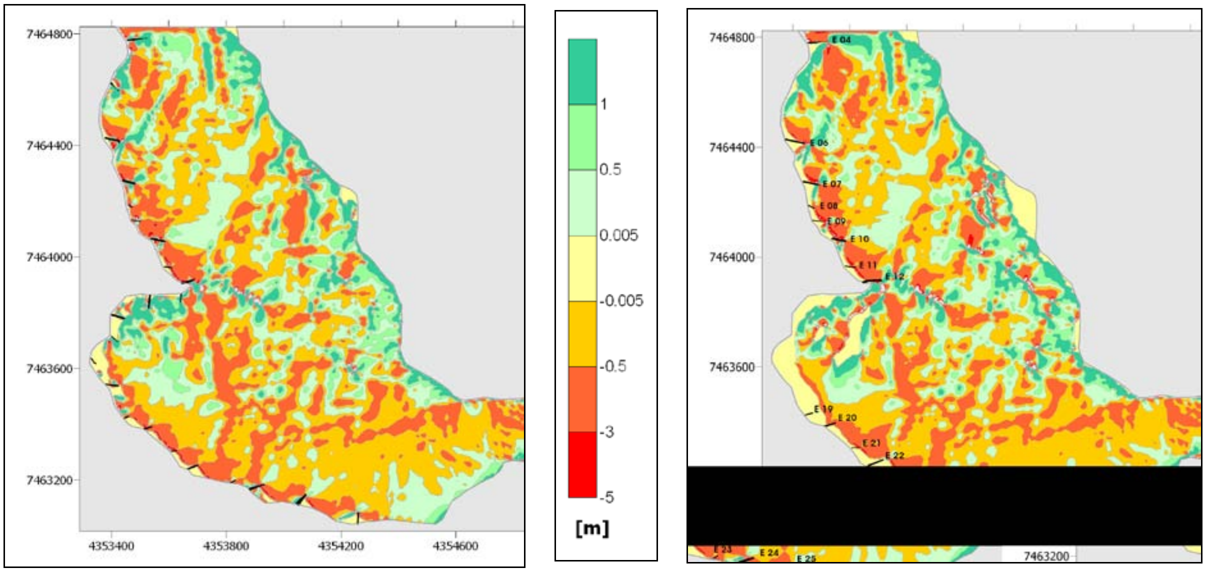
Changes in the groins extension, starting from groin #04, were made once at a time, from upstream to downstream. The changes are summarized in Table 5.1. Note that 8 groins were left as they are, while 12 were extended, for a total length of 195 m (which represents about 18% of the present total groins length). As a sort of compensation, 7 groins could be taken out (and their material reused), as they do not have any functionality. Figure 5.1 shows the comparison between the present situation and the one with the extended groins. The significant increase in the area of the shadow zones gives an indication on the improved performance of the extended groins as bank protection.

Table 5.1. Changes in groins extension for conditioned strategy.

Groin #	***Change***	***Groin #***	***Change***
00	None	14	Taken out
01	None	15	Taken out
02	None	16	Taken out
03	None	17	Taken out
04	None	18	Taken out
05	Taken out	19	+ 10 m
06	+ 15 m	20	+ 10 m
07	+ 10 .	21	+ 10 m
08	+ 5 m	22	+ 25 m
09	+ 25 m	23	None
10	None	24	+ 25 m
11	+ 10 m	25	+ 25 m
12	None	26	+ 25 m
13	Taken out		

5.2 Rational Strategy

To make the interpretation easier, the new groins configuration was built using the one for the conditioned strategy as a reference. As before, changes start from groin #04 downstream. These changes are summarized in Table 5.2. Note that the quantity of groins is the same as for the conditioned strategy (20); 14 of them are left unchanged; 5 are extended, for an additional total length of 85 m (however, this groins configuration would amount to 1,065 m, 4% less than the original (present) configuration; only 4 are moved from their present location, and only 2 are weakly rotated in relation to their current direction. In Figure 5.2 the comparison between the configurations associated to the conditioned and rational strategies is presented. It is observed that with the rational strategy improvements in performance are obtained mainly at the upstream bankline.

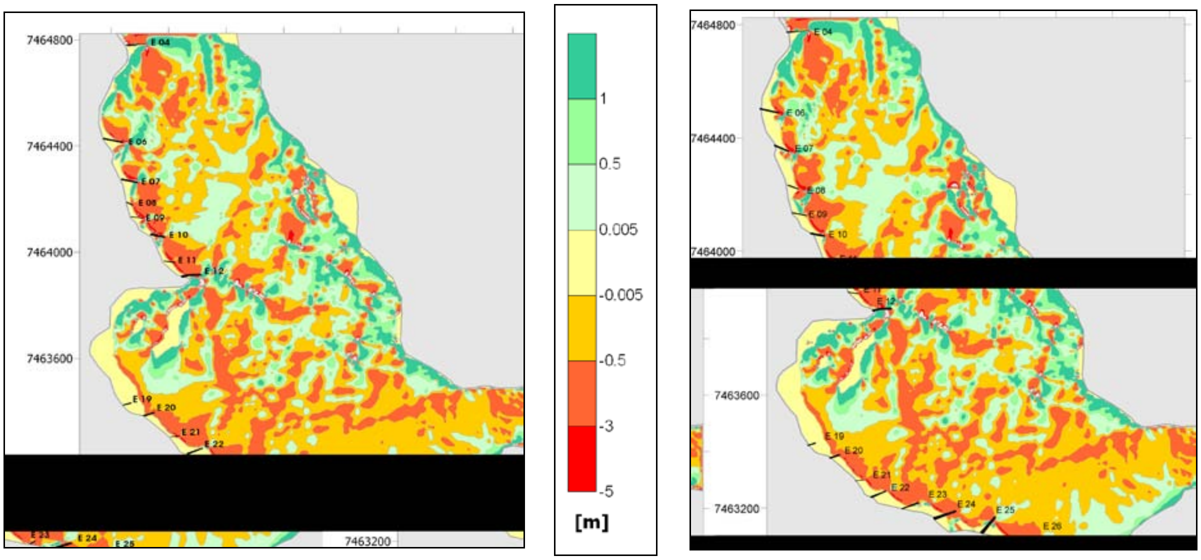


(a) Present groins extension (b) Modified groins extension

Figure 5.1. Bottom level variation after passage of hourly peak of the 50-year flood (8,200 m^3/s) for 1 hour, when groins are extended ('conditioned strategy').

Table 5.2. Changes in groins for rational strategy.

Groin #	*Extension*	*Location*	*Rotation*
00	–	–	–
01	–	–	–
02	–	–	–
03	–	–	–
04	–	–	–
06	–	80 m downstream	–
07	+ 10 m	60 m upstream	–
08	+ 20 m	20 m upstream	10º counterclokwise
09	+ 10 m	–	–
10	–	–	–
11	–	–	–
12	–	–	–
19	–	–	–
20	–	–	–
21	–	–	–
22	+ 15 m	–	–
23	+ 30 m	20 m upstream	10º clokwise
24	–	–	–
25	–	–	–
26	–	–	–



(a) Conditioned strategy (b) Rational strategy

Figure 5.2. Bottom level variation after passage of hourly peak of the 50-year flood (8,200 m^3/s) for 1 hour, when groins are redefined ('rational strategy').

6. CONCLUSIONS

The following are the main conclusions from the paper:

- Modern assessment techniques based on numerical models are available to assist practitioners in the design of groins configuration (length, inclination, spacing) to protect river banks from erosion, providing a rational strategy which can effectively complement established guidelines and expert knowledge.
- When bank failure is triggered by erosion of the near bank river bottom, the use of an integrated hydrodynamic/sedimentologic/morphologic model is the appropriate tool to generate and indicator of bank erosion vulnerability.
- For the particular application presented in the paper, on the Pescado River (Argentina), the methodology was used to optimize the existing groins configuration ('conditioned strategy').

7. REFERENCES

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