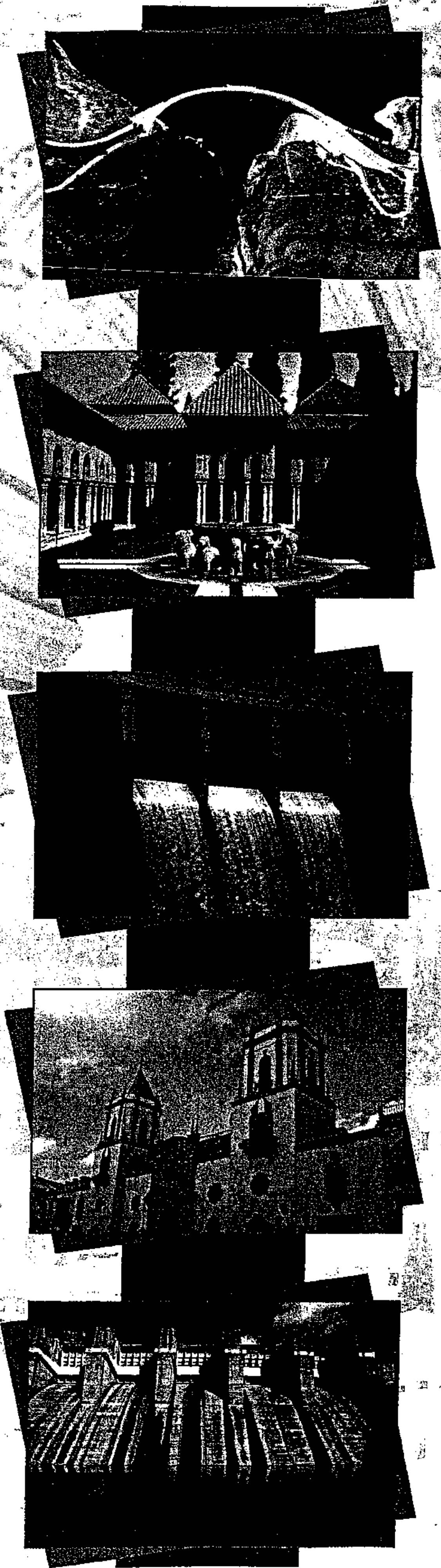
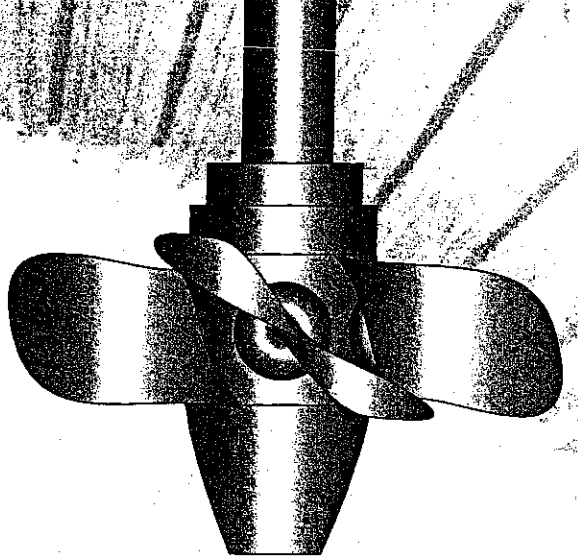


# HYDRO 2007



## NEW APPROACHES FOR A NEW ERA

15 to 17 October 2007
Granada, Spain

# Abstracts

of Conference Papers
(Full papers enclosed on CD)

# HYDRO
# 2007

# NEW APPROACHES
# FOR A NEW ERA

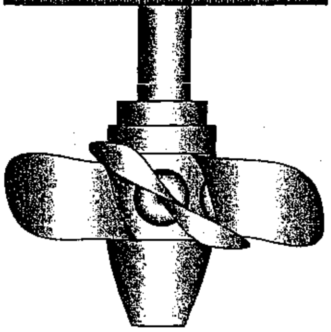
## Abstracts of HYDRO 2007 Papers

As the theme of HYDRO 2007 suggests, hydropower development worldwide has entered a new era, in which projects are planned with greater sensitivity for the environment, and with increased involvement of local stakeholders. The past year (2006-07) has seen far more major developments move ahead in Africa, Asia and Latin America, as well as in some of the original 'hydro pioneering countries' of Europe and North America. In some cases, inhospitable sites in remote areas need to be tackled, and in all cases efforts must be made to maximize investments and protect hydro assets.

The HYDRO 2007 papers represent a unique compilation of expertise from all parts of the world. The broad range of topics cover all practical aspects of hydropower development: reviewing needs and development policies; tackling challenging sites; managing large-scale projects; innovation in small-scale hydro schemes; prospects for marine energy; the role of pumped storage; refinements in machinery design; new approaches to financing; responsibility in planning; environmental protection; upgrading and refurbishment; system management, and contractual issues.

More than 300 papers were submitted this year, and the Organizers together with the Steering Committee have selected 170 for presentation at the Conference. Full papers, including some accepted for publication only, are available on the accompanying CD. This volume of Abstracts provides an overview of the contributions to HYDRO 2007.

# HYDRO 2007



## Granada, Spain
## 15 to 17 October 2007

# ABSTRACTS

PUBLISHED BY

THE INTERNATIONAL JOURNAL ON
HYDROPOWER
& DAMS

Aqua~Media International
Westmead House, 123 Westmead Road
Sutton, Surrey SM1 4JH, UK

## Session 1: Activities, Needs, Challenges and Plans

1.01: The hydro development programme of Iberdrola - *B. Navalon Burgos, Iberdrola, Spain*
1.02: Dams and Hydropower – *Prof Luis Berga, President, International Commission on Large Dams, Spain*
1.03 Capacity building: a critical issue for the African region – *Adama Nombre, Vice President, ICOLD, Burkina Faso*
1.04: China's hydro development programme and update on the Three Gorges scheme in China – *China Three Gorges Corporation*
1.05: Power sector in Vietnam – Potential and hydropower plan – *Lam Du Son, EVN, Vietnam*
1.06: The Rio Madeira scheme: a model for hydro development in Brazil – *E. Nunes da Cunha, J.D. Cadman and E. de Freitas Madeira, Ministry of Mines and Energy, Brazil; S. Alam, Consultant, France*
1.07: Potential for hydropower in Guinea: a better opportunity for sustainable energy development for the country and western Africa – *K. Guilavogui, Ministère de l'Hydraulique et de l'Energie, Rep. of Guinea*
1.08: Considerations on electrification of Africa, with emphasis on the APP region and the hydro potential in Lesotho – *P. Johannesson, Palmi Associates, USA and S. Tohlang, Lesotho Highland Commission, Lesotho*
1.09 The power situation in Nigeria: Progress, problems and prospects – *I. Ekpo, Federal Ministry of Water Resources, Nigeria*

## Session 2: Hydraulic Machinery - Modelling and Research

2.01 : Best practices in model turbine testing – *P. Leroy, P. Pépin and M. Couston, Alstom Power Hydro, France*
2.02: Numerical prediction of flow induced dynamic load in water turbines: recent developments and results – *M. Sick, S. Lais, P. Stein and T. Weiss, VA TECH Hydro Switzerland*
2.03: Francis runner dynamic stress calculations – *A. Coutu and C. Monette, GE Energy, Canada; O. Velagandula, GE Global Research Centre, USA*
2.04: Transient numerical simulation of a horizontal shaft tubular bulb turbine – *H. Benigni and H. Jaberg, Technical University of Graz, Austria; J. Lampl and E. Franz, Kössler GmbH, Austria*
2.05: Measurement and simulation of the 3D free surface flow in a model Pelton turbine – *S. Riemann, W. Knapp and R. Schilling, Technical University of Munich, Germany; R. Mack and W. Rohne, Voith Siemens Hydro Power Generation, Germany*
2.06: Unsteady CFD prediction of von Karman vortex shedding in hydraulic turbine stayvanes – *B. Nennemann and Thi C. Vu, GE Energy Hydro, Canada; P. Ausoni, M. Farhat and F. Avellan, EPFL, Switzerland*
2.07 Lagrangian particle tracking: a powerful tool in designing silt erosion resistant hydro turbine profiles – *V. K. Pande, Voith Siemens Hydro Power Generation, India*
2.08 Investigation of unsteady friction losses in transient flow simulation for large hydropower powerlants – *A. Riasi, Farab Co, Iran; A. Nourbakhsh and M. Raisee, University of Tehran, Iran*
2.09: Numerical study of draft tube of a bulb hydraulic turbine – *J.G. Coelho and A.C.P.P. Brasil Junior, University of Brasilia, Brazil*
2.10: Efficiency and runaway characteristics of a Pelton turbine – *Zh. Zhang and J. Müller, Oberhasli Hydroelectric Power Company (KWO), Switzerland*
2.11: Verification of a flow 3D mathematical model by a physical hydraulic model of a turbine intake structure of a small hydropower plant and the practical use of the mathematical model – *S. Vošjak and J. Mlačnik, Institute for Hydraulic Research, Slovenia*
2.12: The numerical simulation of the inadvertently opening and closing of wicket gates during load rejection tests in one of the operating power plants – *P. Akbarzadeh, Farab Co, Iran*
2.13: A linear characteristic of Francis turbine and its application – *Linming Zhao and Xiaohong Wang, Hebei University,China; Haiyan Wang, Anyang Institute of Technology, China*

## Session 3: Project Finance - New Approaches Bearing Fruit?

3.01: Forget BOOT: It should be BOSS: An alternative approach to hydropower financing – *C.R. Head, Chris Head Associates, UK.*
3.02: World Bank hydro project financing – *J. Plummer, South Asia Energy and Infrastructure Unit, The World Bank*
3.03: African Development Bank support to the hydropower sector – *R.M. Gaillard, African Development Bank, Tunisia*
3.04: EIB financing of hydropower projects – J. *Alario, European Investment Bank, Luxembourg*
3.05: Financing approach for a new era of development in Pakistan – *Z. Majeed, Hydro Planning Organization, WAPDA, Pakistan*
3.06: The Clean Development Mechanism: an opportunity to attract private funds for hydro projects – *X. Kitzinger, EcoSecurities, UK*
3.07: Carbon credit experience in Honduras: Additionality issues – *E.E. Paz Macias, INVERSA, Honduras*

## Session 4: Maximizing Potential by Upgrading

4.01: Feedback on refurbishment of the Stadsforsen and Grundfors turbines, Sweden – *J. Bremond, A. Dumoulin and P. Eberle, Alstom Power Hydro, France*
4.02 Lessons to be learnt from the Drin river cascade rehabilitation project in Albania – J. Gummer, Hydro – *Consult Pty Ltd, Australia; H. Obermoser, Colenco Power Engineering Ltd Switzerland*
4.03: Refurbishment and upgrading of the Chancy-Pougny hydropower plant – *L. Thareau and B. Brusa-Pasqué, Compagnie Nationale du Rhône, France*
4.04: New technical solution for the refurbishment of hydropower plants – *K. Chiba, JPower, Japan*
4.05: Consideration to refurbish five large hydro units in an operating powerhouse based on Guri experience – *D. Flores, CVG EDELCA, Venezuela*
4.06: Rehabilitation and completion works at Bumbuna Falls HEP: a case of interrupted and continued implementation activities - *B. Petry, UNESCO-IHE, The Netherlands and A. Bezzi, Studio Pietrangeli, Italy*
4.07: Adding a 60 MW pump to an existing 240 MW hydropower station – *B. Leyland, Consultant, New Zealand*
4.08: Rehabilitation of the Dokan and Derbendikha hydro plants and dams – *H.A. Hawramany, Ministry of Electricity, Iraq*
4.09: Upgrading multipurpose hydroelectric schemes: Enhancing the assets of Tavropos HEP – *J. Thanopoulos, PPC, Greece*
4.10: Increasing the reliability of a pumped-storage powerplant by the implementation of a new control system – *J. Debor and W. Hörger, Voith Siemens Hydro Kraftwerkstechnik GmbH & Co. KG, Germany; with Scottish and Southern Energy PLC*

## Session 5: Dam Safety - Innovative Approaches to Monitoring and Refurbishment

5.01: Deformation monitoring of earth dams using laser scanners and digital imagery – *A. Berberan and J, Marcelino, National Laboratory for Civil Engineering, Portugal; P. Hilário and J. Boavida, LandCOBA, Portugal*
5.02: Methodology for assessment and refurbishment of buttress dams – *F. Lopez and J. Bosler, GHD Pty Ltd, Australia*
5.03: Paradela dam: hydraulic-operational safety assessment and the design of appropriate measures – *M. Sousa Oliveira and J. Sarmento Gonçalves, EDP Produção – EDP Group, Portugal*

5.04: Rehabilitation of St Marc dam: model studies for the spillways – *M. Leite Ribeiro, J-L. Boillart and S. Kantoush, EPFL, Switzerland; C. Albalat, F. Laugier and A. Lochu, EDF-CIH, France*

5.05: Structural data remote aquisition system for dam safety - *D. Cruz, EDP, Portugal*

5.06: A dam safety project in Brazil – *R. de Abreu Menescal, D.S. Perini, A. Nenes de Miranda and E. da Silva Pitombeira, Ministry of National Integration, Brazil*

5.07: Safety improvement of Kayrakkum dam and hydro plant, Tadjikistan – *A. F. Gurdil, Temelsu International Engineering Services Inc. Turkey*

5.08: Analysis of parameters as a basis for the safe impounding of the Enguri hydro reservoir – *M. Kalabegishvili, Georgian Technical University, Georgia*

5.09: Repairing concrete structures at 95 m water depth using a floating bulkhead at Simón Bolívar (Guri) dam – *J. C. Conde Villasana CVG EDELCA, Venezuela*

5.10: Grouting as a dam safety measure at the Ile-Ife dam project, Nigeria – *E. Ekpo, Federal Ministry of Water Resources, Nigeria*

5.11: Four projects using manually released stoplogs: simple and reliable equipment – *S. Maunier, Hydro-Québec, Canada*

5.12: The importance of Zagros master blind faults in seismic hazard evaluation Changuleh dam case study – *H. Samari, Islamic Azad University, Iran; A. Mobini, Tamavan Consulting Engineers, Iran*

5.13: Innovations which were done in the construction process of Iran's Reis Ali Delvari dam – *M. Amini and M A Varzandian, Mahab Ghodss Consulting Engineers, Iran*

5.14: 1D numerical modelling of the water flow in a low height retention structure provided with seven spillway gaps in case of an accidental high waters – *Gh. Lazar, M. Ion, S.V. Nicoara, A.T. Constantin, A.I. Popescu-Busan, and M.A. Ghitescu, University of Timisoara, Romania*

## Session 6: Hydraulic Machinery - Design, Manufacture and Operation

6.01: Design optimization of a Francis runner – *E. Flores, D. Bazin, L. Ferrando and F. Mazzouji, Alstom Power Hydro, France*

6.02: Francis turbines working with a wide range of head variation – *L.E. Félez Gutiérrez, ENDESA Generación; C. Aguerre Telleria, Voith Siemens Hydro, Spain*

6.03: Kárahnjúkar hydroelectric project mechanical equipment – *S.I. Olafsson, VST Consulting Engineers, Iceland*

6.04: Von Karman frequency excitation caused cracking of the Karun III Francis runner – *A. Aliabadi, IWPC Iran and A. Shamekhi, University of Tehran, Iran*

6.05: Mechanical behaviour of the operation ring of the Francis turbines in Simon Bolivar (Guri) power station – *J.C. Conde Villasana, CVG EDELCA, Venezuela*

6.06: Innovation in main shaft seal design for low to medium head reaction turbines – *D. Edwin-Scott and G. Elliott, James Walker Group, UK*

6.07: A new 3D CFD based design system for water turbine design – *R. Hothersall, Hydroworks Ltd, New Zealand; I. Huntsman, CWF Hamilton & Co Ltd, New Zealand*

6.08: The development of similar welding consumable for welding steel grades GX4CrNiMo 16-5-2 – *N. Friedrich, F. Winkler and J. Tösch, Böhler Welding Austria GmbH, Austria*

6.09: Radial and axial lubricated bearings: experience and development – *Y. Bouvet and J-F. Bertea, Alstom Power Hydro, France*

6.10: 20 years of experience with PTFE-faced tilting pad bearings operating at 11 MPa thrust load – *S.B. Glavatskih, Luleå University of Technology, Sweden; G.A. Paramonov, Energozapchast JSC, Russia*

6.11: Influence of deviation from axial flow symmetry on stream energy conversion in typical ducting of hydraulic pipe turbines – *J. Iwan, Gdańsk University, Poland; Z Krzemianowski, The Szewalski Fluid-Flow Machinery Institute, Poland*

## Session 7: Hydro and Society - Responsibility and Sensitivity in Planning

7.01: Developing better hydro schemes: Recent experiences and future challenges in Lao PDR – *Somboune Manolom, Lao Holding State Enterprise*
7.02: Innovative approaches to improving stakeholder involvement in environmental and social planning: Lessons from projects in Lao PDR and Vietnam – *G. Morgan and C. Mejia, The World Bank*
7.03: Integrating and optimising social and environmental aspects in technical planning – *S. Sparkes, Multiconsult/Norplan AS, Norway*
7.04: Small scale hydro projects contribute to poverty eradication in rural areas of Honduras: A case study – *E.E. Paz Macias, INVERSA, Honduras*
7.05: Hydropower and public acceptance in Nepal – *D.B. Singh, HM Government of Nepal*
7.06: Designing for stakeholders: the case of a 140 MW scheme in an Australian national park – *Paul Caplen, Sinclair Knight Merz, New Zealand*
7.07: Social and environmental assessment of the Bujagali hydropower project, Uganda, under IFC Performance Standards and the Equator Principles – *B. Ogilvie, Tonkin & Taylor International, New Zealand*

## Session 8: Small Hydro: Technology Update and Development Opportunities

### Small and low-head hydro equipment

8.01: Choice of equipment for small hydro – *H. Brekke, Emeritus Professor,NTNU, Norway*
8.02: Application of CFD methods for flow analysis through chosen types of hydraulic turbines for small hydro power plants – *M. Kaniecki, Polish Academy of Sciences, Poland*
8.03: Micro hydropower system for irrigation canal – *T. Nakazawa, J-Power (Electric Power Development Co Ltd), Japan*
8.04: Contreras II hydro plant: Smaller turbine, bigger output – *J. Navarro Torrijos, J. López Nieto and J.C. Elipe Salamdor, Iberdrola SA, Spain*
8.05: Hydroelectric schemes for ultra-low heads – *A. Choulot, R. Cgebak and V. Denis, MHyLab, Switzerland*
8.06: A new turbine for very low head applications and low environmental impact – *M. Leclerc, MJ2 Technologies Sarl, France*

### World perspectives for small hydro

8.07: Development perspectives for small hydro in Burkina Faso – *A. Nombre, Burkina Committee on Dams, Burkina Faso*
8.08: Small hydro in Argentina: promoting economic development and quality of life – *C. Avogadro, Consultant, Argentina*

## Session 9: Civil Engineering Challenges

### Tunnels and challenging ground conditions

9.01: The use of TBMs for tunnel construction at hydro projects – *R. Grandori, Seli, Italy*
9.02: Challenges during the construction and completion phase of the Kárahnjúkar project, Iceland – *G. Pétursson, The National Power Company of Iceland*
9.03: Evaluating the hydraulic roughness of unlined TBM-bored water conveyance tunnels: Kárahnjúkar headrace – *K. M. Hakonardottir and G. G. Tomasson, VST Consulting Engineers, Iceland; B. Petry, UNESCO- IHE, The Netherlands; and B. Stefansson, Landsvirkjun, Iceland*
9.04: Headrace tunnel for the Renun hydro project, Indonesia, constructed with unprecedented groundwater ingress – *H. Kanai, Nippon Koei Ltd, Japan*

9.05: Challenges in tunnelling at the 2000 MW Subansiri lower hydro project in India – *B. Das and J. Kurian, Soma Enterprises Ltd, India; A. Garg, NHPC, India*
9.06: Two inclined pressure shafts driven by a 5 m hard rock double shield TBM at Parbati – *W. Gütter, Jäger Bau GmbH, Austria*
9.07: Péribonka dam, Canada: A dam made possible by modern ground engineering techniques – *S.Balian, Bauer Spezialtiefbau GmbH, Germany*

**Design, construction and site management**

9.08: Numerical analysis and design of the Péribonka powerhouse concrete turbine/generator block – *A. Daly, Tecsult Inc, Canada*
9.09: Design and construction of the first Piano Key Weir spillway at the Goulours dam, France – *F. Laugier, EDF-CIH, France*
9.10: Sloped layered method of roller compacted concrete: cases of Brazilian dams based on scientific research – *N. Goulart Graça, A. de Pádua Bemfica Guimarães and R.S. Machado Bittencourt, Furnas Centrais Elétricas S.A, Brazil*
9.11: Information management on large hydro construction projects – *A. Hodgkinson, SoftXS GmbH, Switzerland; M. Smith, Matrics Consult Ltd, UK, E. Assion, Assion Electronic GmbH, Germany*
9.12: Moving materials by rope supported conveyors and cableways – *P. G. Graziano, G. Zannotti, and A. Contin, Poma, Italy*
9.13: Challenges of construction planning and management in remote areas – *N. Raghavan, D. K. Sharma and K.K.Gupta, Larsen & Toubro Ltd, India*
9.14: Unique application of stoplogs at Kárahnjúkar project, Iceland – *C.K. Sehgal, H. Saxena, and H Perez, MWH Americas, Inc., USA*
9.15: Free surface and pressurized flow regimes in a large water conveyance tunnel: The case of the Jökulsá tunnel for the Kárahnjúkar HEP in Iceland – *A. Baumann and G. Soubrier, Pöyry Energy Ltd, Switzerland; G.G. Tomasson, Reykjavik University, Iceland; B. Stefansson, Landsvirkjun, Iceland*

## Session 10: Pumped Storage - Recent Developments

**Machinery and project design**

10.01: Enhanced energy balancing and grid stabilization through 3-machine-type variable-speed pumped-storage units – *R. Bucher, Lahmeyer International GmbH, Germany*
10.02: Modern design of large pump-turbines – *P. Nowicki, Andritz VA TECH Hydro, Germany; M. Sallaberger and P. Bachmann, Andritz VA TECH Hydro, Switzerland*
10.03: Recent experiences with single-stage reversible pump turbines at GE Hydro – *J.T. Billdal, A. Wedmark, GE Energy, Norway*
10.04: Operation of pumped-storage systems using system dynamics: experience at Ilam – *M.R. Jalali, R. Afzali and E. Eftekhar Javadi, Mahab Ghodss Consulting Engineers, Iran*
10.05: Analysis of fast pumped-storage schemes by hydraulic modelling – *R. Klasinc and M. Larcher, Technical University of Graz, Austria; A. Predin and M. Kastrevc, University of Maribor, Slovenia*
10.06: Selection of double stage pump-turbines for the Yang Yang 817 m head scheme in Korea – *Sang-Yong Lee, Yang Yang PSPP, Komipo, Korea; J-M. Henry, Alstom Power Hydro, France*
10.07: Design of La Muela II 840 MW pumped-storage scheme in Spain – *J.M. Gaztañaga and J. Cervera, Iberdrola, Spain; I. Oliden and J. de Blas, Iberinco, Spain*
10.08: The Lima pumped-storage development project in South Africa – *F. Louwinger, ESKOM, South Africa; T. Basson, BKS, South Africa; B. Trouille, MWH, USA*
10.09: Design of Upper Cisokan: the first pumped storage plant for Indonesia – *S. Yamaoka, Newjec Inc, Japan; N. Mulyanto, PT PLN (Persero), Indonesia*
10.10: Possible locations for pumped-storage hydropower plants in the Republic of Macedonia – *I. Andonov-Chento, Macedonian Committee on Large Dams, Rep.of Macedonia*
10.11: Hydraulic model research of the lower intake of the pumped storage power plant Avče – *P. Rodič, Institute of Hydraulic Research, Slovenia*

## Session 12: Small Hydro in Europe

12.01: Status of small hydropower policy framework and market development in the old and new EU Member States and selected EFTA countries – *C. Söderberg, Swedish Renewable Energies Association, Sweden; P. Punys, Lithuanian Hydropower Association, Lithuania*

12.02: Implementation of the WFC in Italy and experimental studies on reversed flow – *S. Gollessi and G. Valerio, APER (Associazione Produttori di Energia da Fonti Rinnovabili), Italy*

12.03: Evaluation of the profitability of a small hydro cascade – Estimation of upgrading and dam safety costs and economical viability – *J. Laasonen, Fortum Hydropower Services, Finland; T. Kortelainen, Fortum Power and Heat Oy, Finland*

12.04: Varaiable speed operation and control of low head run-of-river SHP plants: European research – *J.I. Pérez, J. Fraile-Ardanuy, J.R. Wilhelmi, J. Fraile-Mora, P. Garcia-Gutiérrez, J.A. Sánchez and J.I. Sarasúa, Technical University of Madrid, Spain*

12.05: Micro hydro in water supply systems – *H. Ramos, Instituto Superior Técnico, Portugal; M. Mello, Hidropower Compony, Portugal*

12.06: Is the smallest the best? – *L. Papetti and C.O. Frosio, Studio Frosio - Studio Associato d'ingegneria, Italy*

12.07: Realization of small hydro electric power plants in existing abutments of irrigation dams in Greece – *S. Rontiris, PPC Renewables SA, Greece*

## Session 13: Managing Sedimentation

13.01: Sedimentation management at the run-of-river Madeira river project in Brazil – *E. Nunes da Cunha, J.D. Cadman and E. de Freitas Madeira, Ministy of Mines and Energy, Brazil; Sultan Alam, Consultant, France*

### Research and modelling

13.02: The effect of turbulence on the sedimentation process in settling basins – *P. Boeriu and D. Roelvink, UNESCO–IHE, Netherlands; Tuan Dobar, Yos Firdaus Simanjuntak, Indonesia*

13.03: Modelling of sediment flushing from reservoirs – *S. Tigrek and B. Yilmaz, Middle East Technical University, Turkey*

13.04: Turbine abrasion and desilting chamber design – *C. Ortmanns,Alstom Power Gydro, Switzerland: S. Prigent, Alstom Power Hydro, France*

13.05: Sediment management at hydro powerplants in the Himalayas – *E. Lesleighter and R. Naderer, SMEC Group of Companies, India*

13.06: Sedimentation in some Iranian reservoirs – *M.R. Rahmanian and M. Jamalzadeh, Mahab Ghodss Consulting Engineers; M.A. Bsanihashemy and P. Badiee, University of Tehran,*

13.07: Study on a new low-level sediment venting system for Dez dam – *A. Khosronejad and M. A. Mohammad Mirzaie, Mahab Ghodss Consulting Engineering; K. Ghazanfari, University of Guilan, Iran*

13.08: Sedimentation study of Poechos reservoir: Analysis and solution of the problems – *B. Zdravkovic, Sindicato Energetico SA, Peru*

13.09: SPSS Sediment remover at the Cuyamel pressurized sand trap, Honduras – *T. Jacobsen, GTO Sediment AS, Norway*

13.10: Different dredging systems and features to handle sedimentation problems in power dams – *P.E.W.M. Anssems, Damen Dredging Equipment B V, The Netherlands*

## Session 14: Maintaining Hydro Assets

14.01: Integrated vibration, process monitoring at the Momina Klisura hydro plant – *M. Hastings and A. Schübl, Brüel & Kjær Vibro, Denmark*

14.02: On-line condition monitoring of the hydro units at Iron Gates I: Possibilities for predictive maintenance – *I. N. Bleier and D.M. Novac, Hidroelectrica S.H. Portile de Fier, Romania; H. Keck and V.A. Meienhofer, VA TECH Hydro AG, Switzerland*

14.03: Development of a hydroelectric plant data acquisition system – *T. Yokoyama, J-Power, Japan*

14.04: Underwater robotic intervention - *M. Blain, J. Beaudry and F. Mirallès, IREQ Institut de Recherche d'Hydro-Québec, Canada*

14.05: Impact of rapidly changing technology on maintenance management practice at hydropower plants in Kenya – *F. Makhanu, Kenya Electricity Generating Co Ltd*

14.06: A study for improving equipment maintenance management for hydropower plants – *Tae-Jin Park and Ki-Won Kim, Korea Water Resources Corporation (Kwater), Korea*

14.07: Making valve maintenance easier: introducing simple methods with great advantages – *A.. Cañellas, IMS SA, Spain*

14.08: Bemposta hydroelectric repowering project – *M.E. Resende, A. Carvalho and V Ribeiro, EDP Gestão da Produção de Energia S.A.Portugal*

14.09: Implementation of the benders decomposition in hydro generating units maintenance scheduling – *I. Kuzle and H. Pandzic, Faculty of Electrical Engineering and Computing, Croatia; M. Brezovec, Hrvatska Elektroprivreda, Croatia*

14.10: On-line monitoring of the hydro units Iron Gates 1: Possibilities to implement predictive maintenance – *I.N. Bleier and D.M. Novac, Hidroelectrica S.H. Portile de Fier, Romania; H. Keck and V.A. Meienhofer, VA TECH, Switzerland*

## Session 15: Environment

### Planning environmental management

15.01: How an environmental management system can bring about concrete improvements in environmental performance - *D. Gray, Hydro Québec, Canada*

15.02: Environmental incidents: zero risk – *J. López Nieto, J. Riesco Canela and E. Enrique Sola Álvarez, Iberdrola SA, Spain*

15.03: Environmental challenges for a sustainable water and energy future – *V. Hobbs, US Army Corps of Engineers, USA*

### Fish protection

15.04: Basin-wide monitoring of survival and fine scale behaviour of acoustically tagged salmon smolts at hydropower dams in the Columbia river basin, USA – *B. H. Ransom, T.W. Steig, M.A.Timko and P.A. Nealson, Hydroacoustic Technology, Inc, USA*

15.05: Environmental assessment of Baixo Sabor hydropower project: Compensatory and mitigation measures – *N. Portal and J. Mayer, EDP, Portugal*

### Experience

15.06 Using flushing flows to control the excess of macrophytes in the lower Ebro river. An appraisal of a five-year experience – *A. Palau and A. Meseguer, ENDESA; R. Batalla and D. Vercat, University of Lleida, Spain*

15.07: Importance of designing regional environmental assessment in the influence area of large dams in Mexico - *T.C. Lecanda. Comisión Federal de Electricidad, Mexico; M.A. Gómez and F.P. Saldaña, Instituto Mexicano de Tecnología del Agua; S. Contreras, Universidad Autónoma de Guadalajara, Mexico; and L.E. Gutiérrez, Comisión Nacional del Agua, Mexico*

15.08: Implementation of catchment area treatment at Uri power station, J&K, India: post-construction assessment and performance evaluation – *U. Bhat, S. Ali Khan and G. Kumar, NHPC, India*

15.09: The touristic potential of dams – *M. Jakob, University of Geneva, Switzerland*

15.10: Environmental impacts of downstream discharges of dams – *B. Khodabakhshi, Mahab Ghodss Consulting Engineering Co., Iran*

15.11: Višegrad HPP impact on Višegrad and Goražde cities riparian zone – *S. Prokić and N. Popović, Jaroslav Černi Institute for Water, Serbia; G. Milanović, EPI or Republic Srpska, Bosnia and Herzegovina*

## Session 16: New Opportunities for Hydropower

16.01: World potential for tidal power – *F. Lempérière, Hydro-Coop, France*

16.02: Development opportunities for tidal current and in-stream energy conversion technologies – *N.M. Nielsen, Kator Research Services, Australia*

16.03: Progress in wave power technology – *J. Weilepp, Voith Siemens Hydropower Generation GmbH & Co Kg, Germany*

16.04: The prospects of using instream flow technology to capture water energy spilling over existing low head dams in the USA – *A. Tseng, Orenco, USA*

16.05: Pumped-storage optimization of wind-hydro renewable energy production in water supply systems – *F. Vieira, H. Ramos, D. Covas and A. B. de Almeida, Instituto Superior Técnico, Portugal*

16.06: Potential opportunities for hydropower in the current mining resources boom – *P. R. Thackray, Consultant, Australia*

16.07: Hydro for bio diesel: an insight to opportunities in Mali - *S. Akuopha, Niger Sahel Energie, Mali*

16.08: Wastewater turbining before and after treatment: the example of Amman City, Jordan – *V. Denis, MHyLab, Switzerland; L. Mivelaz, Groupe E, Switzerland*

16.09: Water recycling for higher efficiency in hydropower generation in Nigeria; Kainji-Jebba case study – *I.U. Emoabino , Eco-Systems Consult Ltd, Nigeria; A.W. Alayande, National Water Resources Institute, Nigeria*

16.10: Hydropower as a part of Corsica's energy programme – *F. Isambert, ISL,* France

16.11: Physical model for the study of a derivation for hydro electric purposes – *F. Rossettini, D. Beggio and M. Arquilla, STE SpA, Italy*

16.12: Hydroelectric development of Baixo Sabor – *M.P. Miranda, EDP Gestão da Produção de Energia S.A..,Portugal*

## Session 17: Turbine Flow Measurement Workshop

17.01: Turbine flow measurement for low-head plants: Owners' options for the 21st Century – *J. Lampa and D. Lemon, ASL AQFlow, Canada; A. Mikhail, HPPE, Canada*

17.02: Case studies of discharge measurements using acoustic scintillation flow meters – *B. Reeb and J-L. Ballester EDF-DTG, France; J. Buermans, ASL AQFlow, Canada*

17.03: Influence of some components of Gibson method instrumentation on flow rate measurement results – *A. Adamkowski, and W. Janicki, Polish Academy of Sciences (IMP PABN), Poland*

17.04: Water turbine tests using the classic pressure-time method with measurement instrumentation inside a penstock – *A. Adamkowski, W. Janicki, G. Urquiza, J. Kubiak and M. Basurto, Polish Academy of Sciences (IMP PABN), Poland*

17.05: Accuracy analysis of the acoustic discharge measurement using analytical, spatial velocity profiles – *T. Staubli, A. Noti, B. Lüscher and T. Tresch, HTA Lucerne; P. Gruber, Rittmeyer Ltd, Switzerland*

17.06: Evaluation of models describing the influence of solid particles on the sound speed and attentuation of pulses in acoustic discharge measurements – *G. Storti and I. Costa, Swiss Federal Institute of Technology; T. Staubli and B. Lüscher, HTA Lucerne, Switzerland; P. Gruber, Rittmeyer Ltd, Switzerland*

17.07: CFD optimized acoustic flow measurement and laboratory verification – *T. Staubli, B. Lüscher and F. Senn, HTA Lucerne, Switzerland; M. Widmer, Rittmeyer Ltd, Switzerland*

## Session 18: System Management

18.01: Comparison of different management models of energy generation enterprises – *M. A. Arantes Porto and R. Andre Marques Furnas Elétricas SA, Brazil*
18.02: Hydropower generation in the electricity market – *J. Santos, H. Azevedo and M.N. Tavares, Rede Eléctrica Nacional SA, Portugal*
18.03: Intelligent energy: How IBM is making energy smarter – *S.J. Clambaneva, PLM Americas (IBM), USA*
18.04: Hydropower and climatological extremes operational forecasting and resource management in the hydropower industry – *R. Spolwind, K. Hebenstreit and F. Fröschl, Verbund/Österreichische Elektrizitätswirtschafts-AG, Austria*
18.05: Drina river basin hydro information system: Simulation model concept – *D. Divac and Z. Simić, Jaroslav Černi Institute for Water, Serbia; N. Grujović and V. Milivojević, University of Kragujevac, Serbia*
18.06: The Serbian-Romanian hydropower system 'Djerdap': Mathematical model – *D. Divac and M. Arsić, Jaroslav Černi Institute for Water, Serbia; N. Grujović and N. Milvojević, University of Kragujevac, Serbia*

## Session 19: Electrical Equipment and Auxiliaries

19.01: Predictive maintenance in hydro generators – *A.T. Garcia, Unitronics SA, Spain*
19.02: Stator winding fixing systems and their influence on the high voltage insulation system for large hydro generators – *G. Lemesch, G. Mußbacher, J. Schönauer and F. Ramsauer, VA TECH Hydro GmbH & Co, Austria*
19.03: Hydro generator uprating/upgrading with requirements for intermittent operation – *L-E. Kämpe, VG Power, Sweden*
19.04: Choice of the level of quality for auxiliaries equipment in a new power station – *O. Tricca, Coyne et Bellier, France*
19.05: Investigations on the water-cooled Svartisen hydro generator after consecutive short circuits – *G. Traxler-Samek and A. Schwery, Alstom Ltd, Switzerland; J.L. Amundsen, Statkraft, Norway*
19.06: Control systems integration according to domain models: Application to hydropower – *R.D. Paulo and A. Carrapatosol, Efacec Engenharia S.A. Portugal*
19.07: Hydro generator rotor temperature measurement system: Application in HPP Vinodol and HPP Dubrava – *G. Orešković, B. Meško, O. Orešković and O. Husnjak, Veski, Croatia; R. Belonbrajić and D. Magić, HEP Proizvodnja, Croatia; M. Husnjak, Faculty of Mechanical Engineering and Naval Architecture, Croatia*

## Session 20: Contractual issues – New Approaches and Experience

20.01: Accelerating the schedule for the generating units at the Caruachi project, Venezuela – *A. Marcano, T. Palacios and M. Balza, CVG EDELCA, Venezuela*
20.02: Review and analysis of a BOT project in Tadjikistan: the case of Sangtuda – *H. Hashemi and M. Vahidi, Farab Co, Iran*
20.03: Build, operate & transfer (BOT) approach for hydropower development – *Partha Pratim Saha and D.K. Sharma, Larsen & Toubro Ltd, India*
20.04: Commom problems faced in new EPC projects in Brazilian dams and solutions found – *R. Machado Bittencourt, N. Goulart Graça and A. de Pádua Bemfica Guimarães, Furnas Centrais Elétricas SA, Brazil*

# Session 21: Penstocks

21.01: Penstock resonance resulting from unstable turbine characteristics – *J.H.Gummer, Hydro-Consult Pty Ltd, Australia*

21.02: Stress relaxation process and monitoring criteria for the Chandoline penstocks exposed to soil movements – *A. Prigent, P. Marietta and P. Bryla, EDF, France; E. Papilloud and L. Toledano, Hydro Exploitation, Switzerland; R. Bertho, Stucky SA, Switzerland.*

21.03: High head low cost penstocks made of glass fibre reinforced plastics – *G. Palsson, Flowtite Technology AS, Norway*

# 18.05

# Drina river basin hydro information system: Simulation model concept

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## Abstract

The Drina River Basin (Drina RB) simulation model, the Drina Hydro Information System (Drina HIS), was developed during the 2002-2006 period at the Jaroslav Černi Institute, in collaboration with the University of Kragujevac/Faculty of Mechanical Engineering. The model development project was supported by the Serbian ministry responsible for water management and the Electric Power Industry of Serbia. The strategic objective of the Drina HIS was to create environment for optimum water resources management and to address and resolve existing and potential conflicts of interest in the region relating to multi-purpose use of water, and the mis-alignment of interests of the various stakeholders in the river basin. The functional objective of the simulation model was to support water management decision making (i.e. to aid users in their assessments of the consequences of various management scenarios and to support planning within various hydrologic, climatic, economic, regulatory and political constraints).

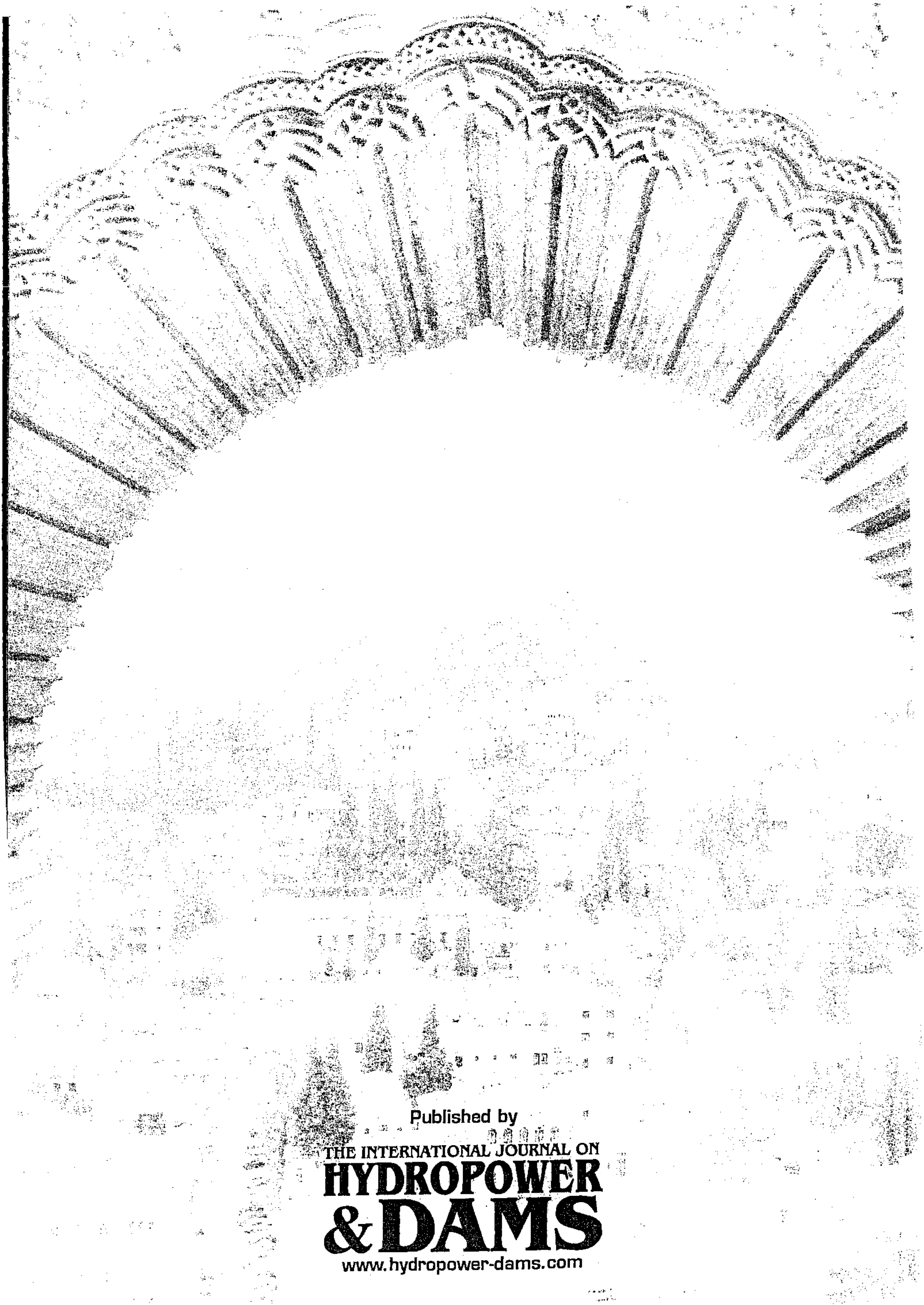
### The Authors

**Dejan Lj. Divac** graduated in Hydraulic Structures at the University of Belgrade, Faculty of Civil Engineering, Department of Structures, Division of Hydraulic Structures. He received his M.Sc. (1992) and Ph.D. (2000) degrees from the same Faculty. Dr. Divac joined the Jaroslav Cerni Institute for the Development of Water Resources in 1985 where he is Director of the Department of Dams and Hydro Power since 1999. He has also been teaching at the University of Belgrade, Faculty of Civil Engineering, since October 2000. Dr. Divac has managed a large number of engineering projects (Chamber of Professional Engineers license no. 310009803). Major projects included high dams (e.g., the Prvonek Dam near Vranje, the Bogovina Dam on the Crni Timok, the Ključ Dam near Lebane, and the Ševelj Dam near Arilje) and hydraulic and roadway tunnels (e.g., Prvonek, Beli Potok, and Palisad). Dr. Divac authored or co-authored more than published 80 papers. His field of expertise includes: design of concrete and earth dams and appurtenant structures, design of tunnels and underground structures, software engineering, and development of water management information systems.

**Nenad A. Grujovic:** Full professor at University of Kragujevac, Faculty of Mechanical Engineering. Director of the Centre for Information Technology (CIT). Spent more than 20 years in software development (FEA, FEM, Database Applications, Computer Simulation, Computer Graphics, Internet Programming, Hydroinformatics, Telemetry). Areas of expertise include advanced structural analysis; linear and non-linear analyses of structures; heat transfer; fluid mechanics; biomechanics: coupled problems; and hydroinformatics. Coordinator of two Joint European Projects under the Tempus Program, national coordinator for the EU FLOODMED Project (monitoring, forecasting and best practices for flood mitigation and prevention in the CADSES region), Project #5D214, CARDS (INTERREG IIIB CADSES), and co-coordinator of the FP6 RRSCD INNCODE 043820 Project.

**Zoran S. Simić** was born in 1972. He graduated in 1999 from the University of Belgrade, Faculty of Civil Engineering, majoring in Engineering Structures. He completed his internship at DOO Hidrovod, a contracting firm from Pančevo. In 2001, Mr. Simić jointed the Jaroslav Černi Institute, Division of Dams, Hydropower Facilities, Mines and Roads. Areas of expertise include hydro information systems (e.g. the HET HIS, the Drina HIS, the Prvonek HIS, and the Iron Gate MM), hydrology (rainfall-runoff processes, etc.), and the design of hydraulic structures. He has started his M.Sc. studies at the University of Belgrade, Faculty of Civil Engineering, Department of Hydraulic Structures.

**Vladimir J. Milivojevic** graduated in Mechanical Engineering from the University of Kragujevac, Serbia, in 2003. He actively participated in a number of national and international projects; major projects include: the Mathematical Model for Hydropower Calculations and Management of the Iron Gate I and Iron Gate II Systems for JP Djerdap, Belgrade, 2004; the Drina Hydrosystem Simulation Model; and software development for the Jaroslav Černi Institute for the Development of Water Resources, Belgrade, 2002. He is currently preparing his master's thesis and is employed as a research assistant at the Faculty of Mechanical Engineering, University of Kragujevac, Serbia.



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THE INTERNATIONAL JOURNAL ON

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# Drina river basin hydro information system: Simulation model concept

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## 1. Introduction

The Drina River Basin (Drina RB) simulation model, the Drina Hydro Information System (Drina HIS), was developed during the 2002-2006 period at the Jaroslav Černi Institute, in collaboration with the University of Kragujevac/Faculty of Mechanical Engineering. The model development project was supported by the Serbian ministry responsible for water management and the Electric Power Industry of Serbia. The strategic objective of the Drina HIS was to create environment for optimum water resources management and to address and resolve existing and potential conflicts of interest in the region relating to multi-purpose use of water, and the mis-alignment of interests of the various stakeholders in the river basin. The functional objective of the simulation model was to support water management decision making (i.e. to aid users in their assessments of the consequences of various management scenarios and to support planning within various hydrologic, climatic, economic, regulatory and political constraints).

## 2. Overview of the Drina River Basin

The Drina RB represents the most significant hydro potential in the Balkans which is not being fully utilized. The surface area of the Drina RB is some 19,570 km$^2$ (Serbia 30.5 %, Montenegro 31.5%, and Bosnia and Herzegovina 37%). The average altitude of the Drina RB is 934 m (altitudes range from 75 m at the mouth of the Drina to more than 2500 m in the highest mountains). The multi-annual average precipitation level in the Drina RB is about 1100 mm, ranging from 700 mm in the northern and eastern portions of the river basin to 3000 mm in the source area of the Lim River in the Prokletije Mountains. The average discharge of the Drina at its mouth is slightly above 400 m$^3$/s. The Drina generally abounds in water in the spring, due to snowmelt and spring rain, and experiences significantly low flows in August and September. The southern portions of the river basin are usually much richer with water than the central and northern portions. Specific runoff from the mountainous areas in the southern portions of the river basin is at times higher than 15 l/s per km$^2$. Specific runoff in the central portion of the river basin ranges from 10 to 15 l/s per km$^2$, while specific runoff in the northernmost, lowland portion of the river basin can be as low as 2 l/s per km$^2$.

To date, 9 hydro power plants (HPP), the Uvac HPP, the Kokin Brod HPP, the Bistrica HPP, the Potpeć HPP, the Piva HPP, the Višegrad HPP, the Bajina Bašta HPP, the Bajina Bašta PS-HPP, and the Zvornik HPP, have been built in the Drina RB; their total installed power is 1932 MW and their average annual output is 6350 GWh.

## 3. Scope and objectives of the Drina Hydro Information System

The Drina RB can accommodate a number of other major hydropower facilities, which would provide an additional annual power output in excess of 7000 GWh. Such hydropower projects would have to include the formation of large reservoirs, which would provide: irrigation of several tens of thousand hectares of farmland in Serbia (Mačva and Srem) and Bosnia and Herzegovina (Semberia); the provision of water supply for several million people and numerous industries in Serbia, Bosnia and Herzegovina, and Montenegro; flood risk attenuation over the entire Drina RB and a portion of the Sava RB; and major water quality improvements. However, even after protracted efforts aimed at better utilization of the Drina RB hydro potential, the future development of the river basin has not yet been comprehensively defined due to a mis-alignment of various stakeholder interests, including those of the governments of Serbia, Montenegro, and Bosnia and Herzegovina (Republika Srpska and the B&H Federation); electric power companies which generate electricity utilizing the Drina RB hydro potential and deliver electricity to different regions; local governments; public utilities; industries; various nature conservation organizations; and the like. As such, the only proper approach is to address the entire basin as a unique water management unit.

The Drina Hydro Information System (the Drina HIS) is a distributed information system which supports water management in the Drina RB and is comprised of several interactive components: integration software for distributed measurement, data acquisition and data archiving systems; simulation model; optimization software; prognostic model; database; user interface; and river basin stakeholder access and communication software. The simulation model is the basic component of the complex software and constitutes the core of the distributed system for Drina RB integrated water management support.

## 4. Spatial decomposition of the river basin, theoretical background and general logic

The model addresses water flow and water use over a large and complex area, which encompasses the entire Drina RB (ca. 20,000 km$^2$). In general, it is important to note the difference between two types of water flow: controllable water flow, or water flow which can be controlled by artificial structures (some of which have already been erected, while others still have to be built), and inexorable water flow which cannot be affected by management decisions. Water enters the system in the form of atmospheric precipitation and is subjected to the user demand (power generation as a function of time or abstraction of specific volumes of water as a function of time). As such, the model includes the generation of runoff, taking into account the effects of snow, topography and soil, as well as all relevant types of linear flow: morphology-based flow along natural streams and flow through structures (dam spillways and outlets, hydro power plants, tunnels, channels, pipelines, etc.). Additionally and very importantly, modeling includes the variation in flow conditions as a function of time, as a result of management decisions (deliveries, priorities and constraints, synchronized with pre-defined power and water demand, as a function of system status parameters) [1],[2],[3].

The model was developed for calculations with daily or hourly time steps.

In view of the spatial and functional complexity of the system, the river basin was broken down into various elements which can simulate different types of water flow (natural and artificially created, uncontrolled and controllable, through existing or potential future structures), based on the following concepts and descriptions [20],[23].

**The hydroprofile** is a model element assigned to each site which holds an existing or will hold a (planned, potential) future dam, water-gauging station, water intake regardless of the type of water use, used water outlet, and river mouth. A hydroprofile is situated solely on a river (natural stream) and its existence determines the control profile of the associated sub-catchment. A modeled hydroprofile can exist in one of the following four options (states): reservoir hydroprofile, run-of-river hydroprofile, inactive hydroprofile, and input hydroprofile.

**The reservoir hydroprofile** is a type of hydroprofile which, as an option, is assigned to each site of the existing and planned dams in the Drina RB. The reservoir hydroprofile is used to model the operation of the reservoir and dam facilities, with due regard being given to all natural and artificially created phenomena encountered during the flow of water, which are described by suitable mathematical equations: transformations within the reservoir, controllable and uncontrolled flow over dam spillways, controllable discharge of water via dam foundation outlets, uncontrolled seepage through the dam and the dam site, uncontrolled evaporation from the water table (water exiting the system), and formation of summary flow downstream from the dam, including setting of biological minimum flow requirements downstream from the hydroprofile.

With regard to increasing demand, the reservoir hydroprofile can function in several ways: the reservoir meets the demand as far as it can, and transfers the unserved demand to upstream assets; the reservoir sets the demand and requests charging to the normal water level; the reservoir meets the demand as far as it can and does not transfer the unserved demand to upstream assets, and the like.

Water deliveries are prioritized by means of a demand serving order of facilities which draw water from the reservoir.

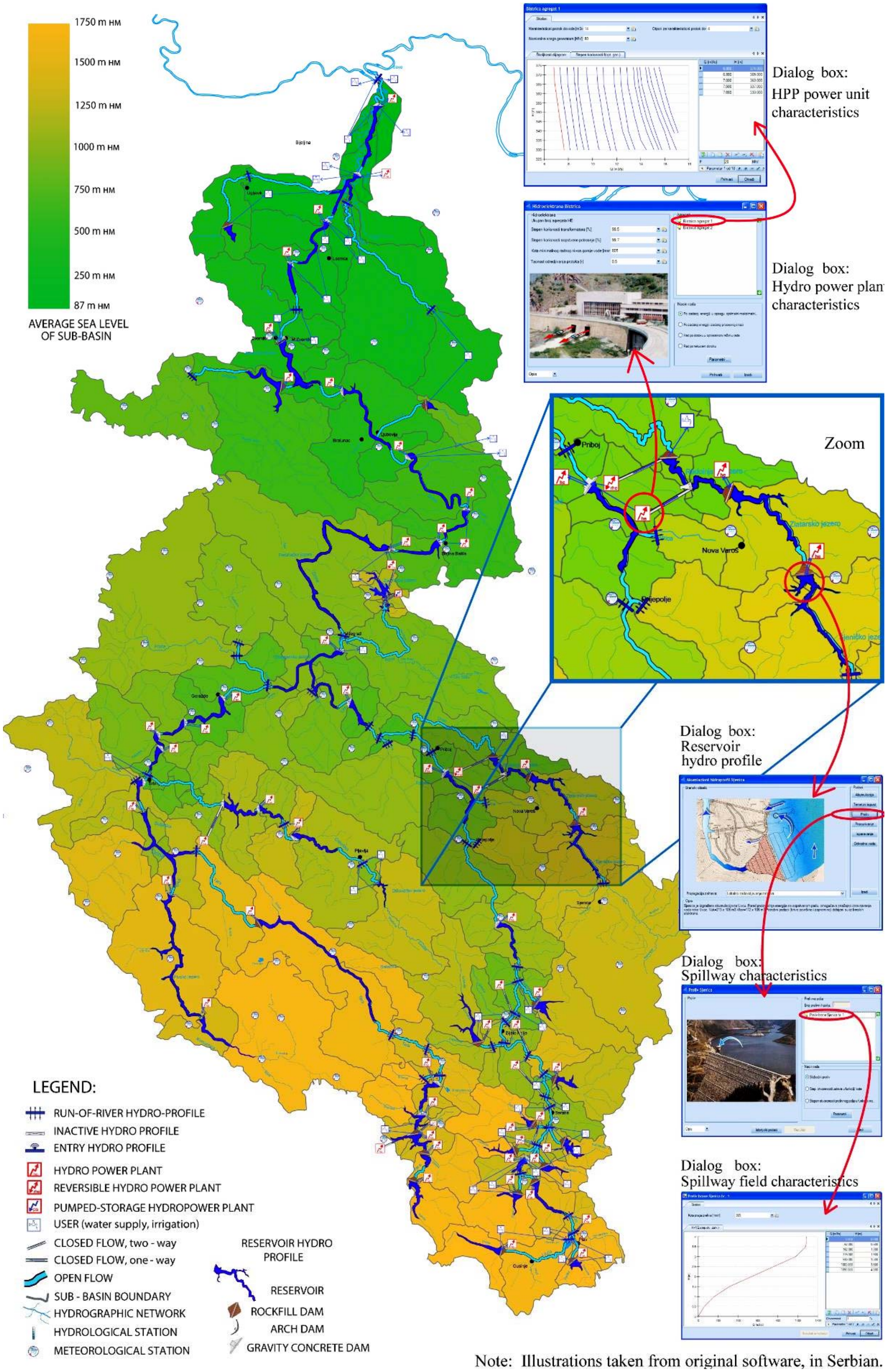
**The run-of-river hydroprofile** is a type of hydroprofile which, as an option, is assigned to each reservoir hydroprofile, but also to each site which holds a water-gauging station, water intake regardless of the type of water use, used water outlet, and river mouth. A run-of-river hydroprofile is used to readily model flow continuity.

**The inactive hydroprofile** is an inactive-state-type of hydroprofile. The associated sub-catchment of the inactive hydroprofile is added to the first downstream active hydroprofile and it represents the meeting point of two river stretches in which it is the initial and ultimate hydroprofile.

**The input hydroprofile** is a type of hydroprofile by which the catchment upstream from that profile is replaced with appropriate inflow. This allows for the observation of any portion of the Drina RB, without the need to configure upstream elements.

**The sub-catchment** is a spatial element determined by upstream and downstream hydroprofiles and river network sub-catchment boundaries. When the downstream hydroprofile is inactive, the sub-catchment of the inactive hydroprofile is added to the first downstream reservoir or run-of-river hydroprofile. Integration of several sub-catchments results in catchments to a particular hydroprofile. The sub-catchment-type element can be used to model: the creation of precipitation in drainage areas (entry of water into the system), the transformation of precipitation into surface runoff and groundwater flow, and the loss of water along drained surfaces (exit of water from the system) [4],[5],[6].

A physically-based hydrodynamic model was adopted. Each sub-catchment was divided into a network of elementary surfaces, or hydrologic response units (HRUs). The HRU is a basic unit used to model the formation of runoff, taking into account the influence of the topography, vegetation and soil.



Note: Illustrations taken from original software, in Serbian.

Fig. 1 *Simulation model schematic*

The first layer simulates water retention by the vegetation cover when precipitation is in the form of rainfall. The second layer, in addition to entrapment by vegetation, simulates water retention within the snow cover. The output from this layer is snowmelt which enters the next layer. The third layer represents the unsaturated layer of soil. It simulates surface runoff and seepage into deeper layers of the soil. Following saturation of the soil and inflow from the previous layer, a portion of the water flows to the aquifer from which groundwater flow or base flow (fourth layer) originates. The fifth layer is in effect the retention capacity of the surface and the topsoil. The rate of flow between layers is determined by the characteristics of the vegetation cover, the topsoil and the hydrogeological strata.

**Closed flow** is an element used for linear modeling of water flow through a tunnel or pipeline, which results in a certain loss of potential energy while retaining equality between the input and output hydrographs. This element creates a link between reservoir/run-of-river hydroprofiles and hydropower elements (HPP, pumping station, and pumped-storage HPP), as well as a link between the reservoir hydroprofiles themselves.

**Open flow** is an element used for linear modeling of water flow in rivers, based on river channel morphology, including the transformation of the input hydrograph into an output hydrograph based on Muskingum/Muskingum-Cunge model equations. This element creates a link between two active hydroprofiles. In the case of an inactive hydroprofile, open flow links the upstream and first downstream active hydroprofile. The open-flow-type unit is determined (generated-regenerated) automatically, based on the active hydroprofile status.

**The hydro power plant (HPP)** is an element used to model the control of power generation and associated water flow. The modeled HPP can be of the run-of-river type (water is drawn and returned within the same reservoir hydroprofile) or diversion type (water is drawn from one and returned to another hydroprofile). The HPP tailwater can be the tailrace of the reservoir hydroprofile, a run-of-river hydroprofile or reservoir. The HPP operation model is based on the use of turbine hill charts (power – net head – discharge), taking into account losses within the HPP's inlet/outlet tract.

The model provides options for several HPP operating modes (depending on the time step and the type of problem being solved). In general, HPP operation can be modeled with a pre-set power or energy demand as a function of time, or based on available inflow, including a wide range of possibilities for the modeling of different management scenarios relating to the distribution of power and discharge among power generating units.

**The pumping station** is an element used to model the management of energy consumption and flow (transfer) of water from the lower to the upper reservoir. The model is founded upon water transfer estimation, based on pumping station requirements and characteristics (net head is used). It is possible to model pumping station operation in several ways; in general, pumping station requirements are based either on energy demand or water level in the lower reservoir.

**The pumped-storage HPP** is an element used to model the management of energy consumption and flow (transfer) of water from the lower to the upper reservoir in the pumping mode, and to model the management of power generation and water flow from the upper to the lower reservoir in the turbine mode. The Drina HIS provides two operating scenarios of a pumped-storage HPP: pre-set energy level for both operating modes (turbine or pump) or pre-set power for the turbine mode and pre-defined program for the pump mode.

**The user** is an element used to model controllable water consumption from reservoir or run-of-river hydroprofiles by users (water supply, irrigation), including partial return of water into the downstream hydroprofiles of the system (except when water is routed away from the Drina RB). The user defines the water demand in the form of a hydrograph. The demand is served according to priorities pre-defined during the configuration procedure. Examples of water uses include: municipal and industrial water supply, irrigation of farmland, cooling of thermal power plant facilities, and the like.

By combining the above-mentioned units, it is possible to create a partial or complete simulation model the Drina RB, which reflects different levels of asset availability and different assumptions relating to the performance of various assets (applies to both existing and future assets).

The most complex configuration of the Drina HIS reflects potentially full asset availability. A complete breakdown of the entire Drina RB results in a system configuration comprised of: 127 hydroprofiles, 127 sub-catchments, 127 open flows, 27 closed flows, 64 HPPs, 2 pumping stations, 2 pumped-storage HPPs, and 43 users (water supply, irrigation). Any other level of asset availability within the Drina Water System can be treated as a sub-system of the system which reflects the ultimate level of asset availability.

## 5. Numerical aspects

Since the simulation of the system involves discrete changes in the system or its environment, which is not continuous over time, a method was developed based on the Discrete Event System Specification (DEVS) approach. The DEVS allows for the representation of all systems whose input/output behavior can be described by sequences of events, provided system states have a finite number of chagnes during any time interval. The DEVS model [15] was developed by *Bernard Zeigler* in the mid 1970s and has, since then, been the most extensively used approach in computer system and network simulations [16], while it is still being researched as a simulation method for continuous physical systems [17],[18]. In addition to the high level of generality, since it integrates continuous and discrete, or hybrid, models, the DEVS provides a suitable environment for the implementation of artificial intelligence [19], which can be used for data based models (experimental, monitoring, historic, etc.).

The formal description of the DEVS atomic model is formally defined as: $M=(X,Y,S,\delta_{int},\delta_{ext},\lambda,ta)$, where X is a set of input events (e.g., in the case of a reservoir, this can be a change in the inflow rate, a change in spillway or foundation outlet control, etc.), Y is a set of output events (in the case of a reservoir, this includes variation in the overflow rate, discharge through the foundation outlet, water level, and the like), S is a set of system status variables (variables relevant to asset status definition, which can be basic or derived, e.g., in the case of a reservoir, the basic status variable is the current volume, while all other quantities, such as the current water level, surface area, etc. are derived from the volume), and $\delta_{int},\delta_{ext},\lambda$ and ta are functions which define system dynamics.

Every possible state s ($s\in S$) has its associated *time advance* which is calculated by means of the *time advance function* $ta(s)(ta(s):S\rightarrow\Re_0^+)$ (e.g., if the difference between the flow to and from the reservoir is $Q$, then the time advance is obtained as $ta=Q/V_{quant}$, that is, it is the time during which the volume will change by $V_{quant}$ if $Q$ is unchanged). The output of the time advance function is a non-negative real number which indicates for how long the status of the system will remain unchanged, in the absence of any external influence.

If the state of the system is $s_1$ at time $t_1$, after $ta(s_1)$ time units (or at time $ta(s_1)+t_1$)), the system will undergo an internal transition and will change its state to $s_2$. The new status is obtained as $s_2=\delta_{int}(s_1)$. The function $\delta_{int}(\delta_{int}:S\rightarrow S)$ is referred to as an *internal transition function* (one example is the change in reservoir volume due to the move to the next point in time $V_{t2}=V_{t1}+(t_2-t_1)Q$ at an unchanged $Q$).

When system state changes from $s_1$ to $s_2$, the output event $y_1=\lambda(s_1)$ is generated. The function $\lambda(\lambda:S\rightarrow Y)$ is referred to as an *output function* (its task is to generate output messages, e.g. on request, the reservoir generates output messages relevant to the operation of other assets – discharge, headwater level, total flow to the reservoir, and the like). Functions ta, $\delta_{int}$ and $\lambda$ define the autonomous behavior of the DEVS model.

If an input event occurs at any time, the system status is changed instantaneously. The new system status does not depend only on input events, but also on the previous status and the time elapsed since the last transition. If the state of the system changes to $s_3$ at time $t_3$, and then an input event occurs at time $t_3+e$, whose value is $x_1$, the new state is obtained as $s_4=\delta_{ext}(s_3, e, x_1)$, where $ta(s_3)>e$ is implied. In such a case, we can say that an external transition has occurred. The function $\delta_{ext}$ ($\delta_{ext}:S\times\Re_0^+\times X\rightarrow S$) is referred to as an *external transition function* (if the reservoir's input port receives a message that the rate of inflow has changed, the reservoir must update its state variables and duration in order to continue to participate in the simulation). External transition does not generate output events.

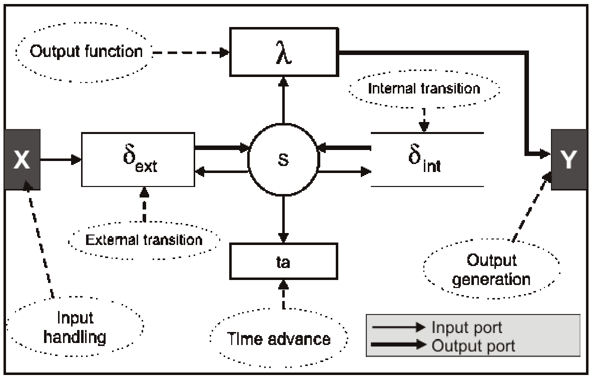


Fig. 2 *Schematic representation of the DEVS atomic model.*

As mentioned above, the DEVS is a model formulated in general terms and it can be used to describe highly complex systems. However, the representation of complex systems, based on stringent principles of physics, using only transition and time advance functions, can become an overly complex procedure. Difficulties arise because it is necessary to predict and describe all possible cases which can be encountered during a simulation, using only a few functions. Of course, complex systems can also be viewed as a number of coupled simple elements. Following coupling, the output events of a sub-system become input events of another sub-system, to which the former is coupled (e.g. if the reservoir and its HPP are bonded into a single bonded system, then the reservoir's output event – which includes information about the tailwater level, current water balance, discharge to the HPP, etc., becomes an input event for the HPP, based on which it computes its status variables, duration, and the like). The theoretical set-up ensures that the coupled system will behave like an atomic model with respect to its environment, such that complex models can be created hierarchically; this is an appropriate basis for the development of object-oriented simulation software [14].

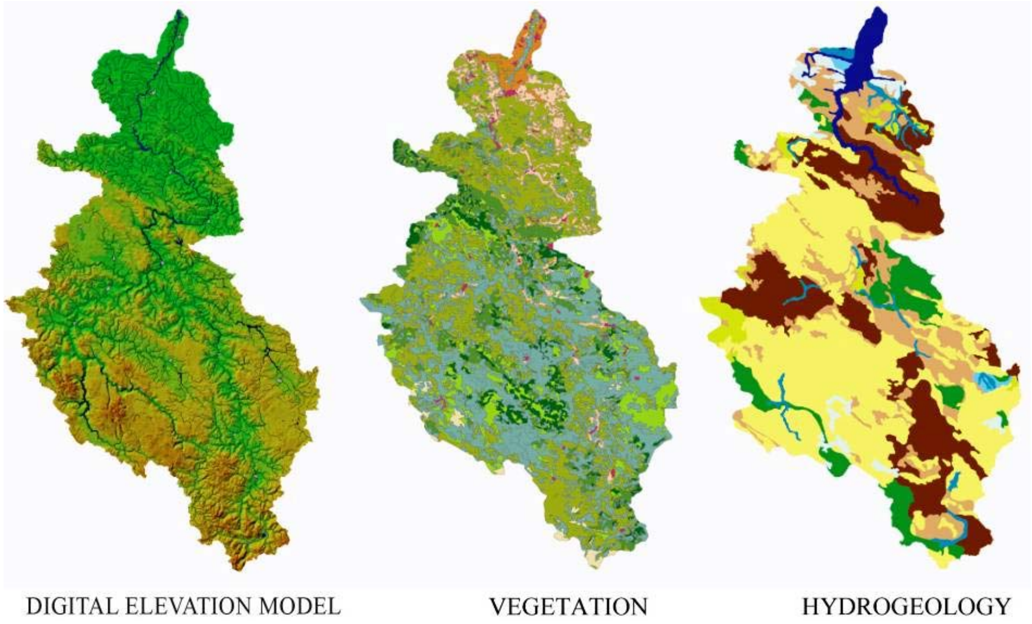
## 6. Database

**Database content and structure.** All data used by the Drina HIS are classified and stored in a database, whose primary task to service models. It contains information about the following: system configuration, performance of existing and potential future facilities (reservoirs, spillways, outlets, HPPs, pumping stations, and the like); catchment areas (topography, vegetation, soil, etc.), the hydrographic network, watercourses, hydro-meteorological stations, hydrology, weather, users, and the like.

In addition to data about modeled assets (127 hydroprofiles, 64 HPPs, etc.), the Drina HIS database contains information about 23654 HRUs with 118270 runoff functions, as well as information about 10 types of vegetation, 8 types of soil, and 6 hydrogeological formations within the Drina RB. The hydrographic network is comprised of 1957 nodes and 1955 river segments.

The Drina HIS database also contains historic data about daily average stages and discharges from 54 monitoring stations within the Drina RB, as well as weather history (precipitation and temperature) from 96 weather stations. All together, this constitutes a data pool with more than 6 million daily values of these parameters. A relation data model was selected for the database. Such a database stores data in the form of tables which are interlinked and accessed via the Relation Database Management System (RDBMS). The Drina HIS database is comprised of 98 tables linked with 87 relations, thus ensuring data consistency in a form adaptable to system changes [21].

**Application of GIS technology.** The database relies on the Geographical Information System (GIS), which allows for association with specific spatial and geographical features. Namely, the database contains voluminous and diverse information in the form of thematic maps (digital ground map, vegetation map, hydrogeological map, zoning map, and hydrographic network), whose elements are linked with the other data (system configuration and the like).



DIGITAL ELEVATION MODEL VEGETATION HYDROGEOLOGY

Fig. 3 *Portion of the model's GIS-content layer*.

Data within the Drina HIS database are arranged in a manner which is most similar to the *ArcHydro* model; this model is a widely accepted standard for the management of GIS data relevant to water resources management [12]. The arrangement of data into layers, and their inter-linkage, leads to a level at which it is possible to use standard models and procedures for the definition and analysis of river networks and catchment areas. The data are complementary. Such a data management system allows for input parameters (such as the effect of vegetation, farming methods, and the like), which are required for the simulation of physical processes, to be computed automatically based on the GIS content.

The accepted and applied *ArcHydro data model* standard for database management also allows the application of standard GIS software, such as *ArcView* or *Autodesk Map* [13]. The compatibility between the database and GIS software is a result of the fact that both the database and the document file produced by the software define objects in the same way. Input data and model outputs are also in a format that is simple for conversion and importing into the Drina HIS database.

## 7. Software platform

The aim of system architecture design and selection of suitable software technologies was to create an open, scalable platform which can equally support a distributed environment, which is currently most often the case.

Since it is a complex system subjected to upgrading and increasing complexity, application scalability is very important and the ability of a large number of users to access the system was kept in mind from the very start. Contemporary information systems handle enormous amounts of data and operating principles established only several years ago are already obsolete. The Drina HIS was not developed on the basis of a conventional single-layer system, in which an application directly accesses the data, but on the basis of a three-layer model [7]. A three-layer model makes a clear distinction between three functional units: the presentation layer, the business logic layer, and the data layer. The presentation layer is the part of the application which is visible to the user. It is implemented via Windows tools which are made available to the user. The business logic layer can be implemented in two ways: in the form of codes within the applications or in the form of an independent web service with which applications communicate via SOAP messages. The first approach was used for the current software version. The data layer represents any database supported by a .NET environment (in this case the Microsoft SQL Server), and communication with the central layer is provided via the ADO.NET environment [8].

**SVG graphical standard.** The *Scalable Vector Graphics* (SVG) language is used to describe two-dimensional graphics in XML [9]. SVG specifies the use of three types of graphical objects: vector objects, figures, and text. The objects may be grouped, their styles may be changed, they can be transformed, etc. In the Drina HIS user interface, the SVG is used for visualization of the simulation model and GIS content, since it is able to handle vector displays and raster data equally, and to thereby ensure full interaction.

**Interoperability of input/output data.** It is important to support major formats for both input and output data. As such, the Drina HIS relies in several areas on the XML format and supports XML record standards for specific document elements.

**User interface.** Full process control is achieved through user/software interaction. Even though the software allows for high automation of the modeling process, the user is able to influence a number of different parameters and to analyze a given problem interactively. A unique user interface has been developed for efficient and comfortable use; it is a mediator between the user and the simulation software. It is modern, graphically oriented software, which interactively and intuitively guides the user through the simulation process via a number of different screens and dialog boxes [22].

## 8. Parameter estimation

In addition to experimental data about the performance of all elements of the system (e.g., reservoir volume curves or turbine hill charts) or information about catchment areas (topography, vegetation, soil, etc.), the database contains „model parameters“ which can be determined by observation or measurement of flow or catchment area characteristics. One example is the Muskingum model parameter of open flow, which has no direct physical meaning and cannot be measured. It is a weight coefficient which is an indicator of the relative importance of downstream and upstream discharges during calculations. As such, model parameters include: 12 parameters for each sub-catchment, 4 parameters for each type of vegetation, soil and hydrogeology; and 2 parameters for each open flow.

These parameters were estimated through optimization (application of evolutionary algorithms), with the goal of achieving the best possible match between computed and measured discharges at a particular hydroprofile where a representative hydrologic station with reliable instrumentation is available. Using known precipitation levels and temperatures, the computed values are obtained through an iterative process (simulation, assessment, comparison, correction, and repeated simulation).

The parameters were estimated over one period (2-3 years), while validation was assessed over a different, independent period [24]. Measured and simulated values for two selected profiles, following calibration, are shown in Fig. 4.

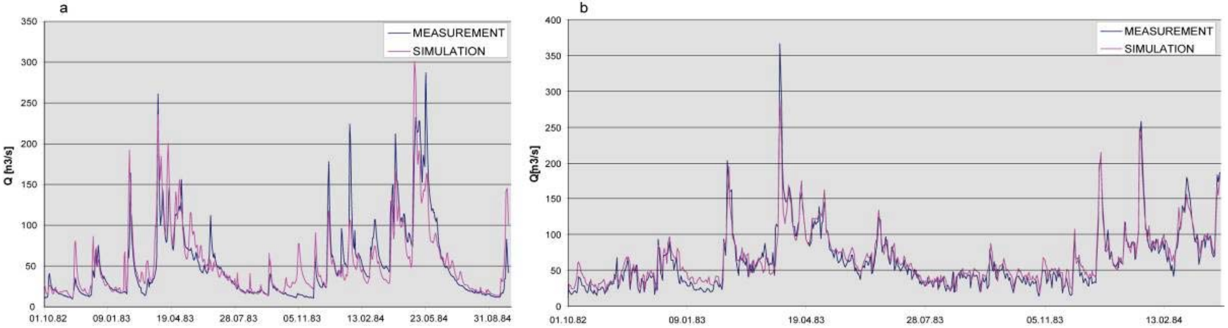


Fig. 4 *Measured vs. simulated values (**a** - Prijepolje Hydrologic Station hydrograph, and **b** - Potpeć Dam hydrograph).*

## 9. Simulation outputs

Simulation outputs include hydrographs and water level diagrams for dam sites, hydrologic station sites and other sites (i.e. all hydroprofiles), hydrographs for dam evacuation facilities, generated electricity, number of operating power units, specific energy, HPP discharge (as well as power output, turbine efficiency and turbine discharge for all active HPP power units), and power consumption for transfer pumping. The outputs are comprised of suitably discretized time series; both are graphical and numerical and can be exported by means of the copy/paste function [22] (Fig. 5 illustrates several simulation outputs).

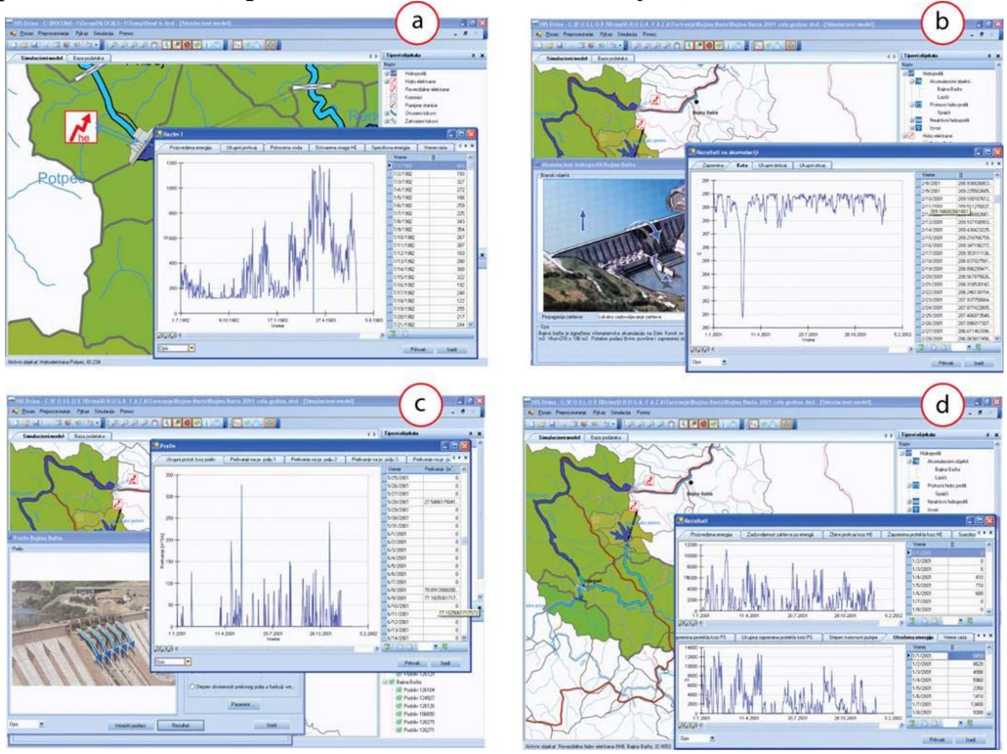


Fig. 5. *Simulation outputs (**a** - Potpeć HPP power generation, **b** - Water level of the Kokin Brod Reservoir).*

## 10. Conclusion

Implementation of the Hydro Information System (HIS), to provide management support, was a very important milestone of integrated management of the Drina RB; the HIS is an IT, technical and expert support tool in decision-making.

The fact remains, however, that a very powerful water resource in the Drina RB is not sufficiently exploited by people who live in the region, mainly because decision makers were unable to recognize and coordinate their joint interests.

The HIS, which supports water management within the Drina River Basin, is a tool by which a more dynamic and more efficient dialog can be established between all river basin stakeholders, at all decision-making stages (spanning from strategic investment planning to operational management) and at all levels of involvement (ranging from measurement and information gathering to the provision of complex evidence in legal procedures).

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