Hydropedological Map of the Republic of Croatia

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Summary

The project Hydropedological Map of the Republic of Croatia was implemented using the ESRI program package. It includes the Basic Hydropedological Map with the attribute database of hydropedological mapping units, pedological and hydropedological profiles and hydrological and hydropedological parameters. The cartographic attribute database of the Basic Hydropedological Map comprises hydropedological units – types of moistening by surface water and/or ground water. The soil water retention capacity of particular hydropedological units varies from 248 to 635 mm/m, water infiltration into soil ranges from 0.01 to 7.32 m/day, hydraulic conductivity for 1 m soil depth is from 0.01 to 6.84 m/day, and from 0.01 to 15.6 m/day for 2 m depth. Annual effective precipitation of 25% occurrence probability varies from 551 to 2294 mm, and that of 75% occurrence probability is between 272 and 1180 mm. Maximum one-day runoff coefficient in the conditions of different soil texture and different vegetative cover ranges from 0.24 to 0.94 (25% probability) and from 0.02 to 0.89 (75% probability). Water deficit in soils of different texture (25% occurrence probability) varies annually from 0.0 to 513 mm/m, and deficit of 75% occurrence probability varies from 30 to 857 mm/m. Water surplus in soils of different texture (25% occurrence probability) varies annually from 57 do 1686 mm/m, and surplus of 75% occurrence probability ranges from 0.0 to 606 mm/m. The Applied Hydropedological Map of the Republic of Croatia comprises priority amelioration units for agricultural land reclamation and management.

Key words

soil, water, hydropedology, maps, GIS

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Introduction

Hydropedology is suggested as an interwined branch of soil science and hydrology that embraces interdisciplinary and multiscale approaches for the study of interactive pedologic and hydrologic processes and properties in the earth's critical zone (Lin, 2003).

Out of the overall territory of Croatia of 56,614 km^2, the total agricultural area in 2002 was 30,338 km^2 with various classes of suitability for different types of farming. There are also 25,291 km^2 of forest land.

The pedological cover of Croatia, including agricultural and forestry land, consists of automorphic soils (31,534 km^2), hydromorphic soils (16,176 km^2), halomorphic soils (5 km^2), and subaquatic soils (3 km^2). Visible karst features - rock outcrops are present on a total area of 7,965 km^2 (Bogunović et al., 1997).

According to Köppen's classification, most of Croatia has moderately warm, rainy climate. Mean annual temperatures are between 4 and 16 ^oC, and annual precipitation ranges from 304 to 2434 mm. Annual precipitation shows a downward trend. Increased temperature is reflected in an increase of effective evapotranspiration. Elevation ranges from sea level to 1,830 m and steep slopes are common. The lithology is quite heterogeneous but is sedimentary rocks are dominating.

The rich natural hydrographic network includes the River Sava basin, the Drava and Danube River basins, and the Littoral-Istrian and Dalmatian river basins. Renewable sources of water in Croatia amount to about 45 billion m^3 per year or 9,500 m^3 per capita. Available renewable amounts of surface water amount to 39 billion m^3/year. Groundwater accounts for only 12% of total water resources in Croatia and it is differently distributed in the classical karst region and in the Pannonian basin, *i.e.*, in the Adriatic Sea and the Black Sea basins (Biondić et al., 1996).

In such circumstances, great concern is caused by the increasing trend of droughts and floods, which have direct influence on soil productivity and biomass production.

The Hydropedological Map of the Republic of Croatia, scale 1:300000, was made mostly by compilation of available semidetailed pedological and supplemental hydropedological data as part of the interdisciplinary scientific-technical project aimed at sustainable management of water resources and soil, notably agricultural land (Vidaček et al., 2004).

The Basic Hydropedological and Applied Hydropedological Maps are important documents of the Croatian Water Management and the National Program of Irrigation and Agricultural Land and Water Management, and comprise the relevant indicators of limitations and/or suitability of the soil-water system and landscape-soil-hydropedology relationships across spatial and temporal scales.

Materials and methods

The project task involved production of the Basic Hydropedological Map with hydropedological units of soil moistening modes and the Applied Hydropedological Map with agricultural land amelioration units, scale 1:300000, with the appertaining attribute databases.

In designing the Basic Hydropedological Map for the needs of defining the spatial distribution and attributes of the hydropedological units database, the following layers – thematic maps of the Republic of Croatia were used: Applied pedological map, scale 1:300000 (Vidaček et al., 2004); Hydrogeological Map, scale 1:300000 (Biondić et al., 1996) and Soil erosion risk in Croatia, scale 1: 300 000, comprising Topographic Map, Drainage Networks Map, Soil Texture and Stoniness Map and Soil Depth Map, scale 1:300000 (Husnjak, 2006); and some pedological and/or hydropedological profiles and the data of meteorological stations.

Cartographic and thematic parameters are grouped in three attribute databases: hydropedological mapping units, pedological and hydropedological profiles, and hydrological and hydropedological parameters.

The attribute database of hydropedological mapping units comprises the classes and types of moistening by surface water and/or ground water within 2 m depth and evaluation of internal soil drainage - hydraulic conductivity.

Dimensions and texture of soil horizons, soil water retention capacity, available soil water capacity, soil depth, horizontal water permeability, infiltration and maximum groundwater table make up the attribute database of 1484 hydropedological and pedological profiles, (Vidaček et al., 2004). For the purpose of this study, data from the attribute database of pedological and hydropedological profiles is interpreted and presented according to the hydropedological units including sandy, loamy and clayey soils.

The attribute database of pedological and hydropedological parameters, based on the data of 36 meteorological stations and on the mode of utilization, includes effective precipitation of 25% and 75% occurrence probability, soil water deficit of 25% and 75% occurrence probability, soil excess water of 25% and 75% occurrence probability for sandy, loamy and clayey soils, and the maximum daily coefficient of precipitation water runoff in the conditions of different vegetative covers.

Applied Hydropedological Map of the Republic of Croatia, scale 1:300000, concerning the attribute database comprise amelioration mapping units according to the priority of reclamation measures and/or management method: drainage, irrigation, dry farming, forests and grasslands, and afforestation.

The project Hydropedological Map of the Republic of Croatia was implemented using the ESRI program package, 1998. Soil Moistening Mode within 2 m depth is based on field measurements and/or judgement supplemented by gleying features in the soil profile and internal soil drainage - hydraulic conductivity according to FAO-ISRIC (1990), FAO-ISRIC (2006). Infiltration rate was calculated according to Schaffer and Collins (1966), water retention capacity and wilting point after Stakman and Harst (1965), soil hydraulic conductivity in the field by the Auger Hole Method (Beers, 1963), maximal daily coefficient of precipitation water runoff after Chow (1960). Soil texture classes were defined according to FAO-ISRIC (1990). Occurrence probability was estimated using the Hazen equation, (Dastane, 1974), effective precipitation after Dastane (1974), precipitation water balance – hydrological estimation of water surplus/deficit in soil according toVidaček et al. (1991). Evaluation of land use value and land use limitations was made according to FAO (1976).

Results and discussion

Concerning the attribute database the Basic Hydropedological Map of Croatia, scale 1:300000 (Figure 1), comprises the spatial distribution of hydropedological units of soil moistening by surface water and/or ground water and the average hydraulic conductivity of different soil horizons within 2 m depth.

Automorphic hydropedological units are moistened solely by percolating surface water, isolated or in combination with precipitation, flood and runoff water, within 2 m depth.

Automorphic excessively drained hydropedological sandy unit is moistened by surface water, very rapid average hydraulic conductivity over 20.0 cm/h and with total gross area of 7,681 km^2.

Automorphic well drained hydropedological loamy unit is moistened by surface water, with rapid to very rapid average hydraulic conductivity of 6.0-20.0 cm/h and with total gross area of 28,222 km^2.

Automorphic moderately well drained hydropedological clay loamy unit is moistened by surface water, with moderately rapid average hydraulic conductivity from 2.0 to 6.0 cm/h and with total gross area of 3,126 km^2.

Hydromorphic hydropedological clay loamy and silty clay loamy units are excessively moistened by slowly percolating and perched water and/or groundwater within 2 m depth.

Hydromorphic alluvial hydropedological clay loamy and sandy clay loamy unit is moistened by surface water and groundwater communicating with the stream water table, with moderately rapid average hydraulic conductivity from 2.0 to 6.0 cm/h and with total gross area 1,550 km^2.

Hydromorphic pseudogleyic hydropedological silty clay loamy unit is characterized by a perched water table within the horizons of slow hydraulic conductivity from 0.2 to 0.6 cm/h and with total gross area of 5,719 km^2.

Hydromorphic pseudogley-gleyic hydropedological silty clay loamy unit is characterized by a perched water table within horizons of slow hydraulic conductivity from 0.2 to 0.6 cm/h and a groundwater table of 0.7 m maximal level within horizons of moderately slow hydraulic conductivity of 0.6-2.0 cm/h in subsurface layers and total gross area of 569 km^2.

Hydromorphic hypogleyic hydropedological silty clay loamy to loamy unit is characterized by a groundwater table up to the surface, within horizons of moderately slow hydraulic conductivity of 0.6-2.0 cm/h and total gross area of 6,172 km^2.

Hydromorphic amphigleyic hydropedological silty clay unit is characterized by a perched water table within horizons of very slow hydraulic conductivity of 0.06-0.2 cm/h, and a groundwater table of 0.8 m maximal level within horizons of moderately slow hydraulic conductivity of 0.6-2.0 cm/h and total gross area of 1,411 km^2.

Hydroameliorated hydropedological unit of different texture is characterized by moistening by groundwater of 0.5 m maximal level within horizons of moderately slow to slow hydraulic conductivity from 0.2 to 2.0 cm/h and total gross area of 1,179 km^2.

Soil moistening mode by surface and/or groundwater within 2 m depth is presented in the Figure 2.

The attribute database of pedological and hydropedological profiles include minimum values of the soil water retention capacity of particular hydropedological units which vary from 248 for light texture soils to 357 mm/m for heavy texture soils, while maximum values are 417-635 mm/m. Minimum values of available water in soils of the listed hydropedological units range from 107 to 177 mm/m, while maximum values are between 266 and 482 mm/m (Table 1).

Minimum values of water infiltration into soil range from 0.01 m/day to 0.05 m/day, while maximum values are between 0.85 m/day and 8.77 m/day, (Table 2).

Minimum horizontal hydraulic conductivity of hydropedological units for soil depth of 1 m (K_1) ranges from 0.01 m/day to 0.09 m/day, while maximum values are between 1.91 m/day and 6.84 m/day. Minimum horizontal hydraulic conductivity of hydropedological units for soil

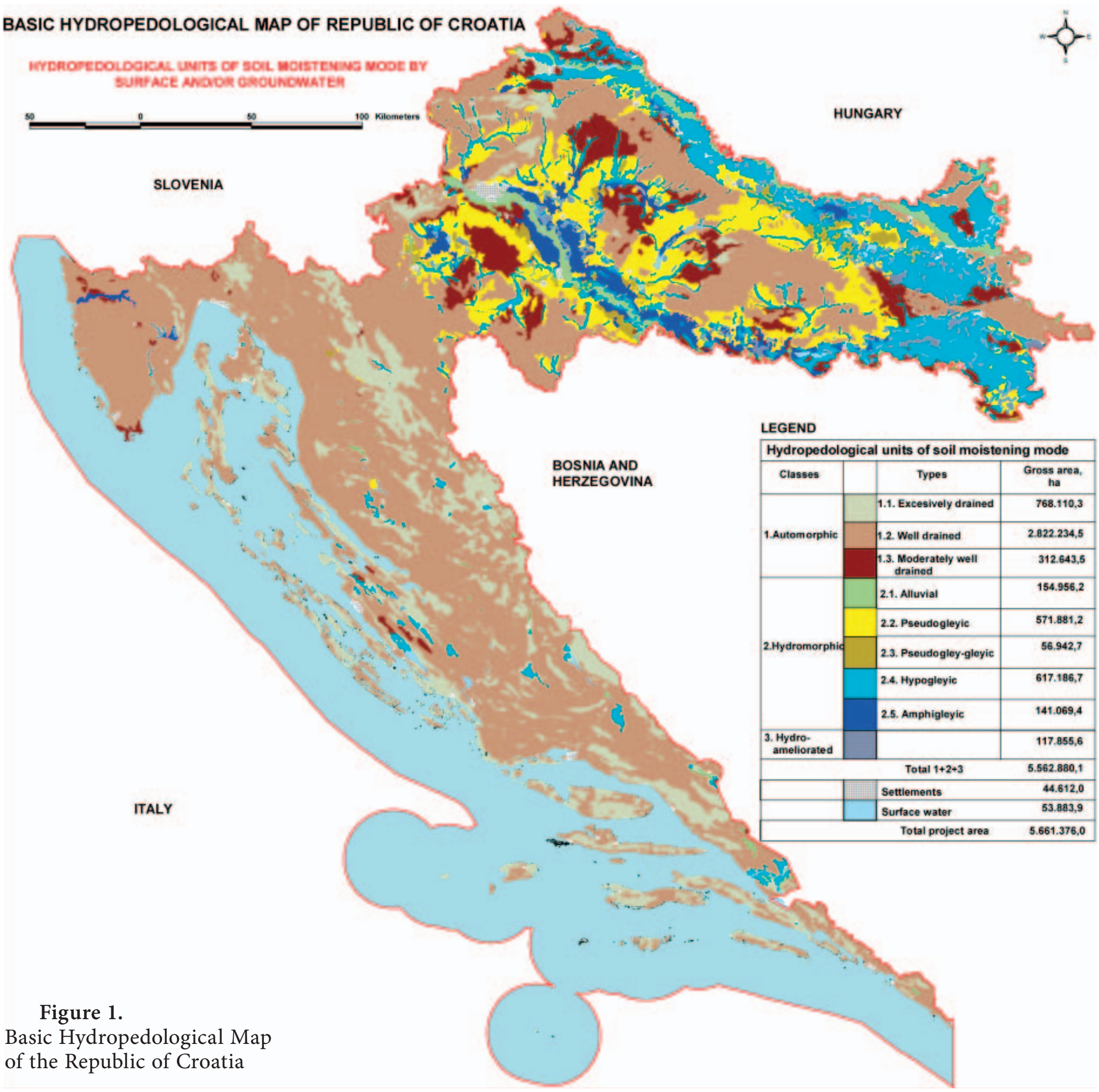

Figure 1.
Basic Hydropedological Map of the Republic of Croatia

Table 1. Soil water retention capacity and available water capacity

Hydropedological units	Water retention capacity (mm/m)			Available soil water capacity (mm/m)		
	Med	Min	Max	Med	Min	Max
Excessively drained, n=8	313.9	294.4	416.6	272.4	177.0	308.9
Well drained, n=92	375.3	247.6	477.6	206.3	143.9	372.9
Moderately well drained, n=25	432.5	356.6	502.8	183.5	107.7	266.1
Alluvial, n=35	412.8	323.9	521.9	190.5	143.6	456.8
Pseudogleyic, n=43	390.4	341.4	481.6	237.6	167.2	328.5
Pseudogley-gleyic, n=9	412.5	317.8	468.7	230.2	135.4	291.9
Hypogleyic, n=115	416.0	323.2	635.1	263.9	107.3	481.7
Amphigleyic, n=46	450.0	308.7	599.6	232.8	116.4	391.6
Hydroameliorated sandy, n=13	396.1	288.0	505.8	297.9	175.0	364.9
Hydroameliorated loamy, n=180	389.9	296.5	553.5	232.7	124.6	392.8
Hydroameliorated clayey, n=64	478.2	347.4	583.6	246.8	134.7	348.6

Med=median; Min=minimum; Max=maximum; n=number of soil samples

Figure 2. Hydropedological units according to soil moistening mode by surface and/or groundwater within 2 m depth: excessively drained type (1.1.), well drained type (1.2.), moderately well drained type (1.3.), alluvial type (2.1.), pseudogleyic type (2.2.), pseudogley-gleyic type (2.3.), hypogleyic type (2.4.), amphigleyic type (2.5.), hydroameliorated type (3)

Table 2. Infiltration rate

Hydropedological unit	n	Median (m/day)	Minimum (m/day)	Maximum (m/day)
Well drained	33	0.95	0.05	8.77
Alluvial	72	0.54	0.01	3.68
Pseudogley-gleyic	13	0.33	0.01	0.85
Hypogleyic	155	0.17	0.01	0.98
Amphigleyic	39	0.05	0.01	5.05
Hydroameliorated loamy	123	0.07	0.01	7.32
Hydroameliorated clayey	12	0.13	0.01	2.83

n=number of hydropedological measurements data

Table 3. Horizontal hydraulic conductivity

Hydropedological units	K_1 (m/day)				K_2 (m/day)			
	n	Med.	Min.	Max.	n	Med..	Min.	Max.
Alluvial	33	0.38	0.09	6.84	22	1.75	0.02	6.00
Pseudogleyic	34	0.23	0.03	4.57	8	0.10	0.02	0.14
Pseudogley-gleyic	25	0.27	0.02	4.58	12	0.64	0.06	2.29
Hypogleyic	157	0.33	0.01	4.66	92	0.91	0.03	15.60
Amphigleyic	82	0.22	0.01	2.40	57	0.92	0.01	3.80
Hydroameliorated sandy	13	0.33	0.01	1.91	8	0.84	0.03	6.20
Hydroameliorated loamy	115	0.34	0.01	4.59	61	0.98	0.02	5.73
Hydroameliorated clayey	34	0.18	0.02	2.37	32	1.06	0.10	3.80

K_1=1 m depth and K_2 = 2 m depth of the hole; Med.=median; Min.=minimum; Max.=maximum; n=number of hydropedological measurements data

Table 4. Effective rainfall

Probability (%)	n	Statistics	Annual (mm)	Months IV-IX (mm)	Months X-III (mm)
25	36	Med	1014.7	466.8	450.0
25	36	Min	551.0	289.0	232.3
25	36	Max	2293.7	862.8	1183.8
75	36	Med	452.5	226.2	192.7
75	36	Min	271.5	95.3	109.9
75	36	Max	1179.6	644.4	558.8

Med.=median; Min.=minimum; Max.=maximum; n=number of calculations-meteorological stations

depth of 2 m (K_2) ranges from 0.01 m/day to 0.10 m/day, while maximum values are between 0.14 m/day and 15.60 m/day, (Table 3).

The attribute database of hydrological and hydropedological parameters include values of effective precipitation of 25% probability of occurrence in the territory of Croatia which vary annually from 551 to 2,294 mm; from 289 to 863 mm in the growing period April-September and from 232 to 1,184 mm in the non-growing period October-March. Values of effective precipitation of 75% occurrence probability vary annually from 272 to 1,180 mm; from 95 to 644 mm in the growing period April-September and from 110 to 559 mm in the non-growing period October-March (Table 4).

Table 5. Maximum one-day runoff coefficient (α)

Soil texture	n	Probability (%)	Crop	Minimum	Maximum	Median
Sandy	396	25	Row crops	0.33	0.84	0.62
Sandy	396	25	Cereals	0.24	0.79	0.54
Sandy	396	75	Row crops	0.07	0.73	0.40
Sandy	396	75	Cereals	0.02	0.67	0.31
Loamy	396	25	Row crops	0.51	0.90	0.75
Loamy	396	25	Cereals	0.44	0.88	0.70
Loamy	396	75	Row crops	0.21	0.83	0.56
Loamy	396	75	Cereals	0.14	0.79	0.49
Clayey	396	25	Row crops	0.66	0.94	0.84
Clayey	396	25	Cereals	0.59	0.92	0.80
Clayey	396	75	Row crops	0.38	0.89	0.70
Clayea	396	75	Cereals	0.30	0.87	0.64

n=number of calculations

Table 6. Soil water deficit of automorphic, hydromorphic and ameliorated hydropedological units of different texture

Soil texture	n	Probability (%)	Statistics	Annual (mm/m)	Months IV-IX (mm/m)	Months X-III (mm/m)
Sandy	72	25	Median	68.8	68.8	0.0
Sandy	72	25	Minimum	0.0	0.0	0.0
Sandy	72	25	Maximum	512.6	506.4	6.2
Sandy	72	75	Median	293.8	283.7	12.7
Sandy	72	75	Minimum	32.7	28.3	0.0
Sandy	72	75	Maximum	857.2	737.7	119.5
Loamy	72	25	Median	67.4	67.4	0.0
Loamy	72	25	Minimum	0.0	0.0	0.0
Loamy	72	25	Maximum	473.6	472.0	9.3
Loamy	72	75	Median	247.5	242.4	10.5
Loamy	72	75	Minimum	34.3	32.2	0.0
Loamy	72	75	Maximum	797.4	677.1	120.3
Clayey	72	25	Median	62.6	62.6	0.0
Clayey	72	25	Minimum	0.0	0.0	0.0
Clayey	72	25	Maximum	459.4	450.4	6.1
Clayey	72	75	Median	231.5	229.8	7.3
Clayey	72	75	Minimum	29.8	28.8	0.0
Clayey	72	75	Maximum	772.0	658.0	114.1

n=number of calculations

Table 7. Soil water surplus of automorphic, hydromorphic and ameliorated hydropedological units of different texture

Soil texture	n	Probability (%)	Statistics	Annual (mm/m)	Months IV-IX (mm/m)	Months X-III (mm/m)
Sandy	72	25	Median	327.2	6.1	301.2
Sandy	72	25	Minimum	57.3	0.0	0.0
Sandy	72	25	Maximum	1685.9	493.8	1192.2
Sandy	72	75	Median	16.7	0.0	15.7
Sandy	72	75	Minimum	0.0	0.0	0.0
Sandy	72	75	Maximum	604.5	116.4	493.6
Loamy	72	25	Median	321.4	4.4	295.9
Loamy	72	25	Minimum	57.3	0.0	57.3
Loamy	72	25	Maximum	1685.9	493.8	1192.2
Loamy	72	75	Median	14.8	0.0	14.8
Loamy	72	75	Minimum	0.0	0.0	0.0
Loamy	72	75	Maximum	606.0	120.3	493.6
Clayey	72	25	Median	315.3	4.0	290.1
Clayey	72	25	Minimum	57.3	0.0	57.3
Clayey	72	25	Maximum	1685.9	493.8	1192.2
Clayey	72	75	Median	14.8	0.0	14.8
Clayey	72	75	Minimum	0.0	0.0	0.0
Clayey	72	75	Maximum	601.5	116.9	493.6

n=number of calculations

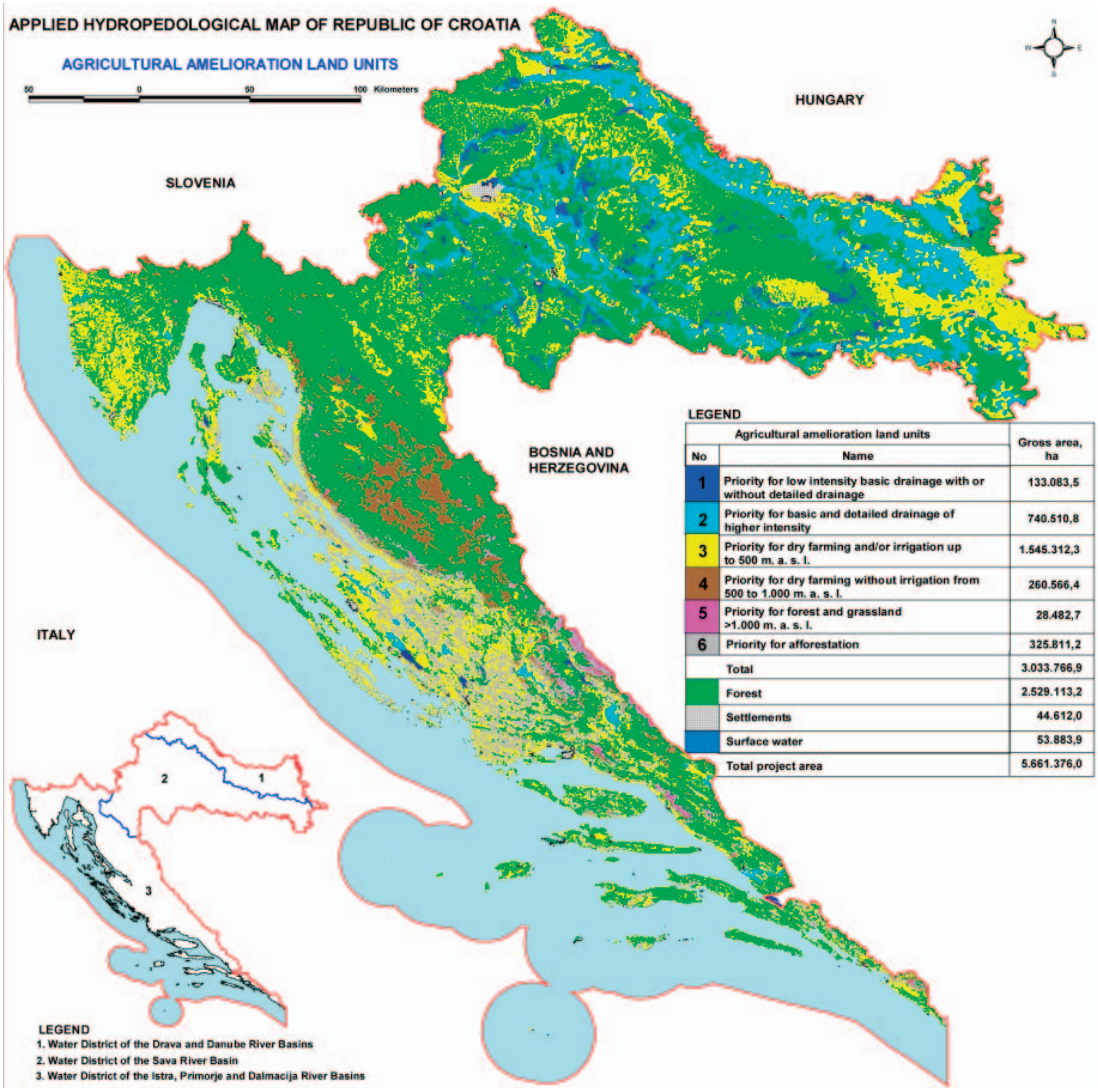

Figure 3.
Applied Hydropedological Map of the Republic of Croatia - agricultural amelioration land units

Maximum one-day runoff coefficient (α) in the conditions of sandy soil, row crops and cereals and of 25% occurrence probability varies from 0.24 to 0.84, while in the conditions of 75% probability from 0.02 to 0.73. Maximum one-day runoff coefficient (α) in the conditions of loamy soil, row crops and cereals and of 25% occurrence probability varies from 0.44 to 0.90, while in the conditions of 75% probability from 0.14 to 0.83. Maximum one-day runoff coefficient (α) in the conditions of clayey soil, row crops and cereals and of 25% occurrence probability varies from 0.59 to 0.94, while in the conditions of 75% probability from 0.30 to 0.89 (Table 5).

Water deficit in sandy, loamy and clayey hydropedological units of 25% probability of occurrence varies annually from 0.0 to 513 mm/m; from 0.0 to 506 mm/m in the growing period April-September and from 0.0 to 9 mm/m in the non-growing period October-March. Water deficit in sandy, loamy and clayey hydropedological units of 75% probability of occurrence varies annually from 30 do 857 mm/m; from 28 to 738 mm/m in the growing period April-September and from 0.0 do 120 mm/m in the non-growing period October-March (Table 6).

Water surplus in sandy, loamy and clayey hydropedological units of 25% probability of occurrence varies annually from 57 do 1,686 mm/m; from 0.0 to 494 mm/m in the growing period April-September and from 0.0 to 1,192 mm/m in the non-growing period October-March. Water surplus in sandy, loamy and clayey hydropedological units of 75% occurrence probability varies annually from 0.0 do 606 mm/m; from 0.0 to 120 mm/m in the growing period April-September and from 0.0 do 494 mm/m in the non-growing period October-March (Table 7).

Applied Hydropedological Map was made for the needs of sustainable use and reclamation of agricultural land and water management in Croatia. The attribute database of this map comprises priority amelioration units for drainage, irrigation, dry farming, forest grasslands, and afforestation (Figure 3).

Priority amelioration unit for low intensity basic drainage, with or without detailed drainage, in the Drava and Danube river basins, covers 146 km^2 or 11%, in the Littoral-Istrian and Dalmatian basins 6 km^2 or 1%, and in the Sava basin 1,178 km^2 or 88.5%. Priority amelioration unit for basic and detailed drainage of higher intensity covers 3,078 km^2 or 41% in the Drava and Danube basins, in the Littoral-Istrian and Dalmatian basins 291 km^2 or 4%, and in the Sava basin 4,036 km^2 or 55%. Priority amelioration unit for dry farming and/or irrigation up to 500 m.a.s.l. covers 2,818 km^2 or 18% in the Drava and Danube basins, in the Littoral-Istrian and Dalmatian basins 7,259 km^2 or 47% and in the Sava basin 5,376 km^2 or 35%. Priority amelioration unit for dry farming without irrigation from 500 to 1,000 m.a.s.l. in the Drava and Danube basins covers 0.35 km^2 or about 1%, in the Littoral-Istrian and Dalmatian basins 2,544 km^2 or 97% and in the Sava basin 61 km^2 or 2%. Priority amelioration unit for forests and grasslands above 1000 m.a.s.l. in the Littoral-Istrian and Dalmatian basins 285 km^2 or 99% and in the Sava basin 0.13 km^2 or about 1.0%. Priority amelioration unit for afforestation in the Littoral-Istrian and Dalmatian basins covers 3,258 km^2.

Conclusions

The Hydropedological Map of Croatia, an interdisciplinary scientific–technical project, comprises cartographic and thematic databases.

The Basic Hydropedological Map of Croatia comprises spatial analysis and interpretation of hydropedological conditions from the aspect of soil moistening by surface water and/or ground water, as well as hydrological and hydropedological parameters – soil capacity for water, infiltration, hydraulic conductivity, groundwater regime, annual and seasonal water surplus/deficit in sandy, loamy and clayey soils, and maximum daily runoff coefficient for different vegetative covers.

Concerning the data of Basic Hydropedological Map including soil moistening by surface water and/or ground water, then soil capacity for water, infiltration, hydraulic conductivity, groundwater regime, annual and seasonal water surplus and/or deficit in the soil, amelioration units of different priority for reclamation measures and agricultural land management have been defined within the Applied Hydropedological Map of Croatia. Priority for low intensity basic drainage, with or without detailed drainage, has been estimated for 1,331 km^2, priority for basic and detailed drainage of higher intensity for 7,405 km^2, priority for dry farming and/or irrigation up to 500 m.a.s.l. for 15,453 km^2, priority for dry farming without irrigation from 500 to 1000 m.a.s.l. for 2,606 km^2, priority for forests and priority for grasslands >1000 m.a.s.l. for 285 km^2, and priority for afforestation for 3,258 km^2.

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