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MARSHLANDS OF "LASY RYCHTALSKIE" FOREST PROMOTION COMPLEX - PRESENT STATE AND PERSPECTIVE OF CHANGES

Summary

The aim of the present work is a description of a multi-year complex field research (hydrological, chemical and geotechnical) carried out in the area of the "Lasy Rychtalskie" Forest Promotion Complex "Lasy Rychtalskie". The work focused on characterizing the present state, forecasting future changes, as well as indicating the stability threats which the areas face.

Forest promotion complexes are functional areas of a particular ecological, educational and social significance. The Lasy Rychtalskie Complex is situated within the grounds of the Syców Forest Inspectorate and its name is taken from the section called Rychtal. The area of the forests is famous for its *Pinus sylvestris* L ecotype, as well as unique genetic values, confirmed by scientific research.

The field investigations were carried out on the marshlands of the forests in focus. Three experimental plots, microcatchments and 6 transects transverse to the forests roads, situated either within the area of the catchments or in their close neighbourhood, were selected for the detailed research. The selected catchments are situated on the marshlands. 51 groundwater measurement wells, alongside with 3 Thomson overflows situated on watercourses were installed on the experimental plots. Soil samples were collected from all drillings for standard laboratory tests of mechanical, physical, chemical and physico-chemical properties.

The marshlands in focus are characteristic for their high storage capabilities. The annual outflow is relatively low, reaching about 4 % of the annual precipitation, and it occurs only in the winter half-year and May. It can be concluded on the basis of the obtained results that the Nash model delivers satisfactory results of the catchment outflow simulation for forest marshlands. The effective precipitation calculated basing on the SCS-CN model finds a limited application for marshlands. Groundwater can be found shallow at the depth of approx. 1m below ground level. Water relation changes forecast for the investigated areas, expressed by groundwater level changes, was based on the negative annual atmospheric precipitation trend. It was assumed that significant changes in marshland ecosystems would occur in the situation of at least 50 % decrease of the present mean groundwater level. It will take about 100 years. Pragmatic action to be taken should prevent from the outflow of the water from the areas. The work presents an easy to apply method of evaluating potential storage capability of forest areas. It utilizes, among other components, standard data stored in bases built during forest management practices.

The carried out chemical tests did not reveal any excessive accumulation of chemical pollutants either in soil or both ground and surface waters of the Complex.

Dirt roads based on marshy subsoil did not meet, in the period of the whole year, the bearing strength requirements defined for forest roads. The bearing capacity of hard paved not-improved roads depended on the groundwater table level in the subsoil.

Key words: forest marshlands, technical infrastructure

INTRODUCTION

The ”Lasy Rychtalskie” Forest Promotion Complex (with its area of approx. 48 thou. ha) comprises the forests of two inspectorates of the Regional Directorate of State Forests in Poznań; namely Syców and Antonin, and those of the Experimental Forest Complex in Siemianice. The area is located on the grounds belonging to the III Wielkopolsko-Pomorska Region**,** the 9 Province of the Zmigrodzko-Grabowska Valley**,** as well as the V Silesian Region of the 2 Breslau Province.

Marshlands are here defined as abundantly moisturized forest areas which include surfaces described in valuation terms as swamp coniferous forest (Bb), swamp mixed coniferous forest (BMb), swam mixed broadleaved forest (LMb), alder swamp forest (Ol), and ash-alder swamp forest (OlJ), flooded broadleaved forest (Lł,) The final decision to classify an area as a marshland follows after local forest examination. The marshy habitats cover the following areas of the total acreage: Antonin 1.2 %, i.e. 239 ha, Syców 1.0 %, i.e. 221 ha, and Siemianice 6.3 %, i.e. 375 ha [Miler *et al*. 2005].

Some worldwide recognised scientific centers suggest that the process of intensive accumulation of chemical pollutants, taking place both in organic soils and waters of marshy areas, may have been going on for a long period of time; the supposition corresponds to trace elements and dioxins generated by industrial centers. It has been found out for example that the level of accumulation of lead, cadmium, nickel and zinc present in English marshlands significantly exceeds the permitted level regarded as safe to the environment. The British scientists warn that the forthcoming climatic changes may bring about drying up of the existing marshlands and releasing a high amount of toxic compounds as a result of water and Eolithic erosion.

The Polish forest areas are the country's least human-polluted and transformed ecosystems. A vast range of chemical investigations was carried out of soil, water and tree plant bioindicators of the marshy areas in focus. This was due to the predicted hazard resulting from the release of chemical pollutants from the grounds subjected to the process of drying up.

The existing road network is a significant element of the marshy lands technical infrastructure. Both its density and technical state of forest roads provide, to a high degree, conditions for proper management of forests. Mineral marshy areas, particularly organic ones, are characterized by low bearing capacity which is further lowered at the time of high groundwater levels. Approx. 90 % of forest roads are soil-surfaced roads and they become unsuitable for traffic when moisture is abundant. And thus the issue of improving the present state of forest marshy roads becomes significant.

The aim of the work is to describe and present the results of the multi-year complex field investigations (hydrological, chemical and geotechnical) carried out in the marshy areas of the Rychtal Forests Complex. The final aim is to define the present state, to forecast the changes, as well as indicate the possible danger to the stability of the areas.

MATERIALS AND METHODS

Description of the experimental plots and general range of investigations

Three experimental plots were selected for the detailed investigations. They were microcatchments (8.58, 30.61 and 32.00 ha) which are almost entirely situated on forest marshlands (Fig. 1). This is the most significant element in the proposed experiment since the core of it is an evaluation of the outflow from the defined area with excessive moisture.

The field research was begun in 2004. It comprised, among others, limnigraphic water levels measurements in watercourses at Thomson weirs, weekly ground water levels measurements, collecting samples of surface and ground water, as well as soil for chemical determination (twice a year) and testing the bearing capacity of road; it was carried out applying the VSS apparatus (periodically). The meteorological data were obtained from the Siemianice station.

An assumption of the water regimes changes for the area was worked out analyzing the temporal trends of mean annual air temperatures, as well sums of annual atmospheric precipitation. The Nash conceptual model [Miler 1994] was employed to model the storm flow runoff from the marshy areas. Calculation of the effective rainfall was performed by SCS-CN method. An evaluation of the Forest Complex areas water retention potential was attempted focusing on the potential capabilities of the area to retain water.

SCS-CN model

The SCS-CN model is a conceptual model of the total precipitation separation, worked out in the 50's of 20th century by the Natural Resources Conservation Service in the USA. The model is based on the assumption that the factors decisive in separating the total precipitation into effective precipitation causing storm flow runoff, are dependent upon the catchment cover, type of soil, and initial moisture before precipitation causing storm flow occurs. The non-dimensional indicator CN is a synthetic parameter combining the features. And thus the effective precipitation is a function of abovementioned catchment features [USDA-NRCS 1985].

The basic assumptions of the model state the equality of the proportions of actual storage (*F*) to maximum catchment storage (*S*), as well as effective precipitation to the total precipitation decreased by the initial loss (1), balance assumption stating that the total precipitation (*P*) is the sum of the initial loss (*Ia*), actual infiltration (*F*) and effective precipitation (*Pe*) (2). Parameter *CN* is bounded by empirical dependence with (*S*) parameter. Additionally the value of the initial loss (*Ia*) is bound to the potential storage maximum value (*S*) (3) [Mishra, Singh 2003] basing on the principle of equality of empirical dependence.

Thus:

$$\frac{F}{S} = \frac{Pe}{P - Ia} \tag{1}$$

$$P = Ia + F + Pe \tag{2}$$

$$Ia = \lambda \cdot S \tag{3}$$

It was empirically proved that $\lambda \in [0; 0.3]$, in the original model it was accepted that λ is 0.2 [USDA-NRCS 1985].

Simple transformations deliver the following:

$$Pe = \frac{(P - 0.2 \cdot S)^2}{P + 0.8 \cdot S} \quad \text{for } P > Ia \tag{4}$$

$$Pe = 0 \quad \text{for } P \leq Ia \tag{5}$$

Maximum storage *S* is bound with the non-dimensional $CN \in [1; 100]$, for *P*, *Pe, S* values expressed in millimeters, *S* is calculated from the dependence:

$$S = 25.4 \cdot \left(\frac{1000}{CN} - 10 \right) \tag{6}$$

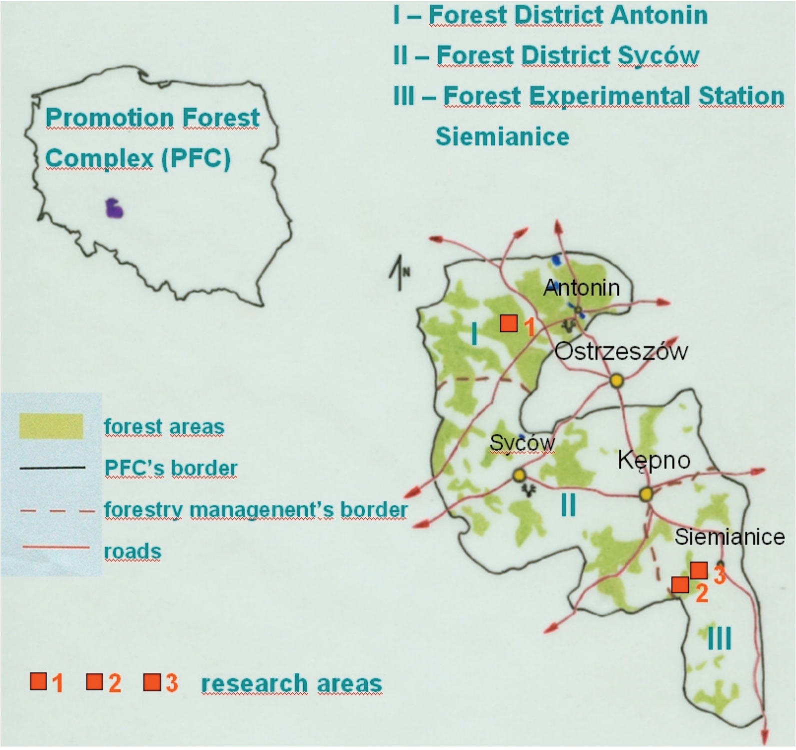

Figure 1. Location of the Promotion Forest Complex "Lasy Rychtalskie" and research areas

The SCS-CN method was initially developed for agricultural areas. Forest was regarded as a category of land use which was homogenous in its structure [Mishra, Singh 2003, Okoński 2006]. The methodology, basing on the features of the forest environment, for calculating parameter *CN* for Polish forest ecosystems was suggested by Okoński [2006]. The suggested modification of the method utilizes hydro-meteorological data, as well as data of the area cover features obtained from a spatial unit – catchment or a few catchments, and makes possible calculating *CN* values ascribed to the physico-geographical conditions. The basic equation of the modified SCS-CN method enabling calculating the *CN* parameter value, based on the original version of the method into the parameter values ascribed to a given catchment or special unit is given below:

$$CN_{emp} = \frac{100}{a \cdot (\frac{100}{CN} - 1)^{b} + 1} \tag{7}$$

where:

CN_{emp} – empirical value of CN parameter,
CN – parameter value according to the original method,
a, b – empirical coefficients.

Making use of pairs of corresponding parameter CN values i.e. the values calculated basing on the original method (CN), as well as calculated for a given catchment on the basis of empirical data (CN_{emp}), coefficients a and b are calculated for the equation (7) from a regression relationship.

Basing on the parameterized equation, the values of CN are recalculated according to the original method taking into consideration the given catchment outflow conditions in relation to the varied features of forest cover.

Potential storage capabilities

Both climatic and non-climatic physiographical elements modify the local capabilities of water storage. The elements such as: relief, soils and geological structure, drainage network, stagnant waters and plant cover (species and age structure, etc.) condition potential water storage capabilities. Evaluating of potential storage capability consists in ascribing to each elementary homogenous area a parameter which considers a total impact of most significant physico-geographical parameters [Miler *et al.* 2001]. A subsection is accepted here as an elementary surface. It facilitates almost direct utilization of the data stored in the databases constructed during forest management activities [Grajewski 2006]. Each subsection was ascribed certain parameters which were regarded as crucial in determining its potential storage capability. The following parameters were regarded as determinants: mean ground slope [%], habitat moisture type [-], distance from drainage network [m], distance from stagnant waters [m], mean weighted soil filtration coefficient [$mm \cdot s^{-1}$], stand compaction index [-], type of soil cover [-], stand age [years], type of forest habitat [-], and stand dominating species [-]. Then the ranges of change of each parameter values were divided into three classes corresponding to: ”*low*”, ”*medium*” and ”*high*” storage capability, coding them as: 1, 2 and 3. ”*Low*” (code 1) potential storage capability of a given subsection was associated with the dry type of habitat’s moisture, short distances from drainage network, high soil filtration coefficients, low index of forest compaction, exposed soil cover, young stands, dry oak habitats, as well as deciduous species while ”*high*” potential storage capacity of a given sub series was associated with marshy type of habitat moisture, long distances from the drainage network, low values of soil filtration coefficient, high ratio of stand compaction, moss soil cover, mature stands, marshy and riparian habitats, as well as coniferous species. What followed was summing up the code values of all the parameters separately for each of the sub series. And thus a certain numerical value was obtained for each of the sub series being an indicator of potential storage capability from the range (*min* = 10, *max* = 30). This results from a simple calculation: *min* = 10(*characteristics*) · 1(*min codes*) = 10, and *max* = 10(*characteristics*) · 3 (*max code value*) = 30. Spatial distribution of the indicator, in the form of a map, enables indicating the areas of "low", "medium" and "high" potential storage capability of the analysed area.

Chemical investigations

Within the framework of the chemical investigations the following steps were taken:

1. Determination of major soil, ground and surface water pollutants indexes,
2. Estimation of heavy metal accumulation on the basis of soil magnetic susceptibility distribution in both horizontal and vertical system,
3. Determination of dioxin content in soil.

Methods of determination of major indexes of soil, ground and surface water chemical pollutants:

- reaction pH: PN-90/C-04540,
- $ChZT_{Cr}$: PN-74/C-04578,
- ammonia nitrogen: PN-C-04576,
- nitrite nitrogen PN-C-04576,
- nitrate nitrogen: PN-C-04576,
- sulfates: PN 74/C-04566,
- chlorides: PN-75/C-04617,
- orthophosphates: PN-88/C-04537,
- Cu, Zn, Cd, Fe, Co, Cr, Ni, Pb, Mn: (ASA): PN-92/C-04570,
- sodium and potassium: PN-ISO-9964-3,
- calcium: PN-91/C-4551,
- magnesium: PN-91/C-4562,
- hardness: PN-71/C-04554,
- electrolytic conductivity: PN-EN 27888.

Magnetic susceptibility is an easily measurable geophysical variable describing ability of a given substance to magnetizing changes under an influence of an exterior magnetic field.

The procedure of measuring magnetic susceptibility is based on an evident relation between an increase of magnetic susceptibility and the content of heavy metals in soil. Strzyszcz [2003] comments that soil surface magnetic susceptibility ranging from 30×10^{-5} to 50×10^{-5} may point out that the amount of at least one metal exceeds the boundary value permitted for forest soils. Magnetometry is a method alternative to expensive geochemical methods. The method is specially useful in forest areas where a long-period deposition of pollutants (including magnetic particles) is not disturbed by agro-technical practices.

Soil magnetic susceptibility was analysed applying the determination of surface and vertical distribution of ferromagnetics.

The surface measurements were carried out applying a magnetic susceptibility meter equipped with an English field sensor MS2D produced by Bartington Instruments Company, integrated with GPS Pathfinder American system manufactured by Trimble firm. The measurement equipment was provided by the Institute of Environmental Engineering of the Polish Academy of Sciences in Zabrze. The measurements values were described in non-dimensional units of magnetic susceptibility.

Vertical distribution of magnetic susceptibility was analyzed using a Czech produced SM 400 magnetic susceptibility meter, type - ZH Instruments – Brno. Measurements of value κ in vertical system were analyzed down to the depth of 20 cm with resolution equal to 0.2 mm.

Dioxins come into existence as an undesirable side-effect of some industrial or combustion processes, or as a result of various damages. The basic source of dioxin emissions into the environment are industrial refuse, herbicides, pesticides, and transformer oils releases.

Dioxins are also produced as a result of an uncontrolled coal combustion which takes place in stoves, boiler rooms and refuse heaps containing chlorine bounded in both organic and inorganic form. Fires can also be a source of the elements. Dioxin content identification in soil was carried out by help of gas chromatography technique in combination with mass spectrometry with a double fragmentation of the investigated molecule applying MAT GCQ and GC-MS/MS type [Grochowalski 2000] appliances.

Dioxins were determined using the unique equipment in the Laboratory of Trace Analyses of the Faculty of Engineering and Chemical Technology, Cracow University of Technology.

The level of toxicity of the analyzed samples expressed as standardized value TEQ, was calculated applying the so-called equivalent toxicity coefficient (TEF) on the basis of the chemical analyses of mass content of congeners PCDDs and PCDFs having chlorine atoms in positions 2, 3, 7 and 8.

Forest road bearing strength

The aim of the research was determining the influence of the water table level in soil subgrade on the bearing strength of forest road pavements.

Bearing strength investigations were carried out on roads with soil and non-rehabilitated paved surfaces built from debris, slag and melaphyre breaks tone. Constructions of non-rehabilitated paved surfaces were founded on a filtering off course having 0.2 m thickness.

All the experimental road sections were founded on soil-marsh subsoil, and bearing strength investigations were carried out in the conditions of extreme groundwater table level in the subsoil. VSS apparatus with a pressure slab of 0.30 m in parameter was applied to determine bearing strength and index I_o was also calculated.

RESULTS AND DISCUSSION

Water relations

Annual outflow from the areas in focus is relatively low approx. 4 % of the annual sum (Tab. 1). The watercourses disappear seasonally – in hydrological years 2004/2005 and 2005/2006 there was an observed outflow during the periods of respectively 202 days ((15.11.2004–5.6.2005) and 192 days (1.12.2005–10.6.2006). In the period of the investigations no typical, i.e. basing on surface runoff, storm flows were observed. Normally they last in the investigated catchments for no longer than a few hours during heavy rainfalls. The observed storm flows – increased outflows of rain-thaw or rain type-were fed by both subsurface and ground outflows. The above proves a relatively high storage capability of the marshlands in focus. (stands, forest bed, ground depressions, soils).

Average groundwater levels (51 wells) are placed shallow i.e. 97.5 cm below ground level, with standard deviation 55.5 cm. Outflows occur in watercourses when groundwater levels are higher than their approximated mean annual values.

Nash model-a conceptual catchment model- was used to model the observed precipitation-storm flows incidents*:* N-identical, linear reservoirs with time-constant T [Miler 1994]. A proper evaluation of effective precipitation is crucial in case of precipitation-outflow models. Effective precipitation can be calculated on the basis of coefficients of storm flow outflows i.e. quotients of storm flow outflows and sums of precipitations causing the storm flows. Then the results of Nash model simulation are fairly good for the investigated catchments. An exemplary result of simulation for ditch G-8 catchment is presented in Fig. 2.

The following trends were calculated basing on the data from Siemianice (1957-2006): mean annual air temperatures (+0.041 ^{o}C/year) and annual atmospheric precipitation sums (–1.573 mm/year). The above trends are significant statistically respectively at the significance level α=0.05 and 0.25. Positive air temperature trend will undoubtedly stimulate evapotranspiration growth which depends on many factors, among others access to water. It can be thus assumed in the forecast that evapotranspiration will not undergo significant changes. The outflow from the investigated areas is insignificant so it can be not taken into consideration in the prediction.

Table 1. Equilibrium water balance of marshlands of the Forest Promotional Complex "Lasy Rychtalskie" in hydrological year 2004/2005

Months	Component of water balance [mm]			
	Precipitation	Evapotranspiration	Outflow	Change of water storage
XI	77.5	10.7	0.5	+126.6
XII	22.9	11.3	0.5	+104.0
I	43.4	14.3	1.2	+51.0
II	8	13.9	2.2	+26.2
III	23.9	17.9	13.3	+5.8
IV	27.9	46.4	1.9	-15.0
V	93.3	78.8	0.8	-54.7
VI	33.7	80.5	0.0	-119.2
VII	58.0	90.0	0.0	-72.4
VIII	61.6	72.9	0.0	-36.4
IX	32.3	46.8	0.0	-25.8
X	8.2	25.5	0.0	+15.0
Year	**534.6**	**509.1**	**20.5**	**+5.0**

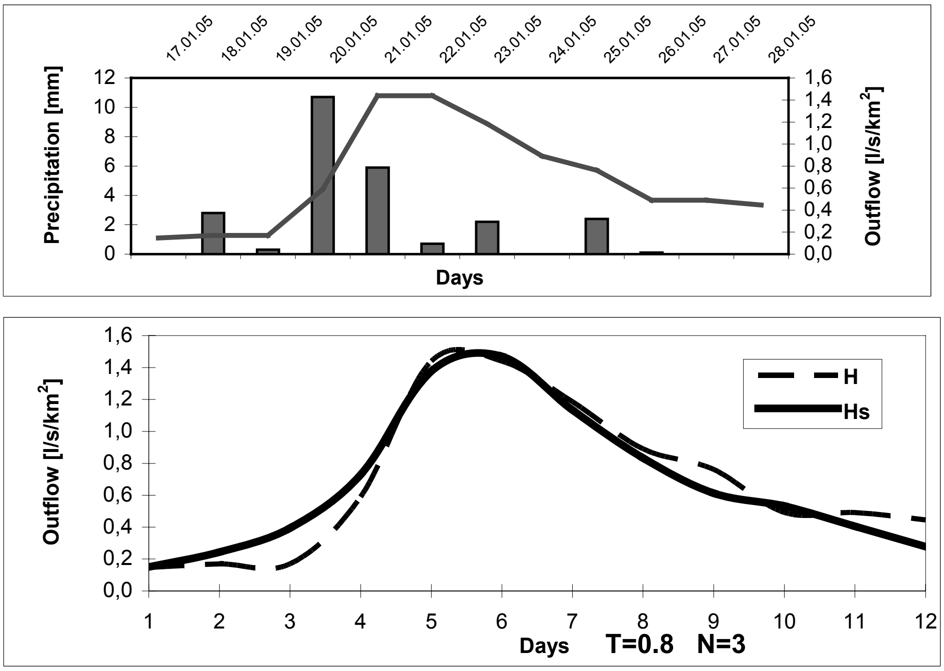

Figure 2. Example result of storm flow modeling in marshlands on the Promotion Forest Complex "Lasy Rychtalskie" (H – measured outflow, Hs – simulated outflow)

Finally the prediction of water relation changes in the area in focus, expressed by groundwater level changes, can be founded on negative atmospheric precipitation trend. If it is assumed that significant changes in marshy ecosystems will occur alongside with a decrease of average groundwater level by approx. 50 cm (50% of the present average groundwater level), as a result of decreasing annual atmospheric precipitation sums, it can be calculated that this will happen in about 100 years.

Alongside with the accepted assumptions and soil porosity in the aquifer of 30 %, after 100 years decreasing precipitations will bring about lowering of groundwater levels on average by 46.3 cm. The above calculations show only the order of magnitude corresponding to the period, after which such a drain up of forest marshlands is probable that will lead to changes in their character, and they will not stay abundantly moisture habitats.

Modelling of effective precipitation

Modelling of effective precipitation accompanied by the modified SCS-CN model was carried out on the basis of the empirical data gathered in 2005 hydrological year from the forest marshland catchment (ditch G-8) having the area of 32 ha. Storm flows episodes, as well as precipitation sums, connected with them were taken into consideration in the period of the year.

Modelling assumptions were met by three storm flow incidents, which were qualified for the modelling procedure i.e. the episodes from the periods 17.01–28-01.2005, 06.04–21.04.2005, 01.05–14.05.2005. The procedure of calculating parameter *CN* empirical values was carried out, taking into consideration initial moisture values for precipitation episodes, in agreement with factual soil moisture (soil before precipitation bringing about storm flow – AMC). Results of subsequent precipitation episodes are gathered in Tab. 2.

Table 2. Results of modelling for ditch G-8 catchment

Rainfall episode period	Period	Actual antecedent moisture of soil before rainfall (AMC)	Average empirical value of *CN* parameter for the catchment	Maximum storage	Total rainfall	Direct runoff	Empirical runoff coefficient	Direct runoff according to the model	Runoff coefficient according to model
	t	AMC	*CN*	*S*	*P*	*Pe*	*A*	*Pe*	*A*
	[days]	[-]	[-]	[mm]	[mm]	[mm]	[-]	[mm]	[-]
17.01-28-01.2005	8	III	76.4	78	25.1	0.56	0.022	1.12	0.0446
06.04-21.04.2005	3	II	33.9	495	24.3	2.75	0.113	Condition of the model $P>0.2\cdot S$	
01.05-14.05.2005	9	I	20.4	991	42.4	1.69	0.04		

Results of effective precipitation modelling with help of SCS-CN model in the version adjusted to the conditions of the catchment cover can be viewed only in estimating categories.

The features of ditch G-8 catchment (marshland) are unfavourable for creating surface and subsurface outflow. And thus SCS-CN model has noticeably limited applications for marshlands.

Potential storage capabilities in the Marianka Experimental Forest Range

The map depicting spatial variability of potential storage capability index of the Experimental Forest Range areas is presented in Fig. 3. The analysis of the index shows its high spatial variability. The map can be utilized e.g. while designing plans for increasing water storage for the area.

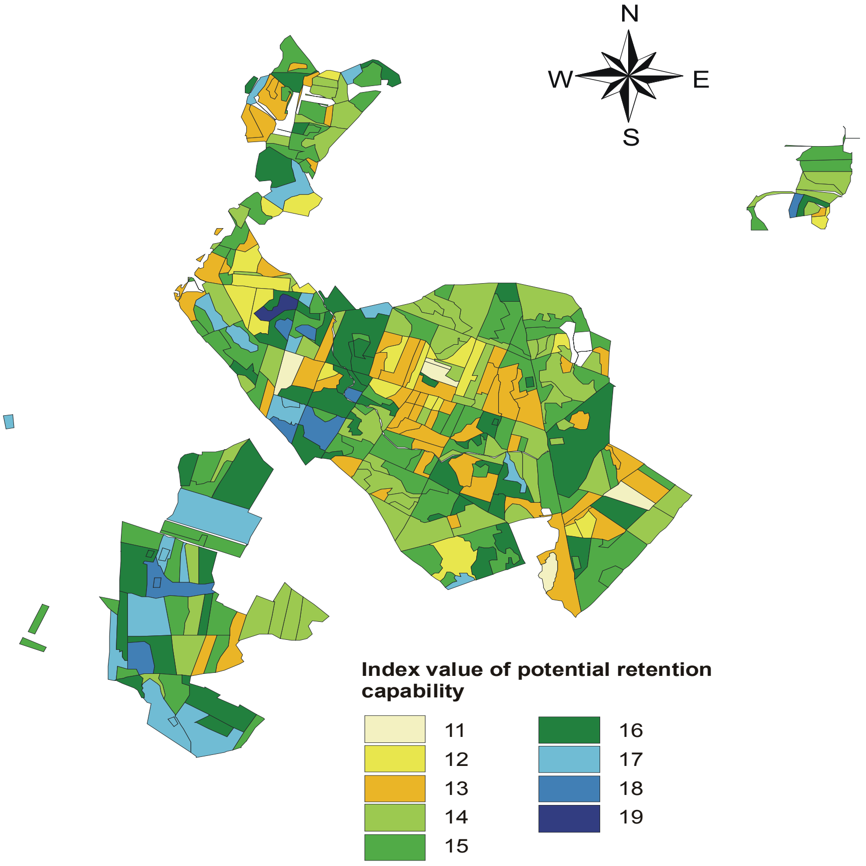

Figure 3. Spatial distribution of the index of the potential storage capability of the forest areas of the Forest Experimental Range "Marianka"

Chemical investigations

As a result of the carried out chemical tests of both soils and waters of the marshlands in the Mariak and Marianka Forest Ranges no strong cumulation processes of anthropogenic origin pollutants were found. The obtained research results were compared with corresponding standards of soil quality (Decree of the Minister of Environment of September 9, 2002 defining standards of soils and grounds (Dziennik Ustaw nr 02.165.1359 of October 4, 2002)), and boundary values of surface and underground water quality indexes, the manner of monitoring procedures, as well as ways of interpreting the results and presenting the levels of the waters (Dziennik Ustaw nr 32, poz. 283 and 284)).

Water-soil environment of the analysed marshlands poses no danger to the neighbouring forest complexes from the chemical point of view [Miler et al. 2006].

As far as grounds are concerned, the content of heavy metals, apart from cadmium, was found to be within the value range accepted for areas protected by legal regulations concerning the cleanest natural reserves belonging to group A. The content of cadmium at some research plots insignificantly exceeded the permissible values defined for cadmium, but did not exceed the values for group B areas i.e. arable, forest and afforestation areas. The investigated soils were characterized by a high variability of iron concentration.

An increased cumulation of heavy metals (apart from iron) was not confirmed by the initially conducted magnometric investigations. It is assumed that non-polluted soils are characterized by a natural magnetic susceptibility (below 30×10^{-5}). Magnetic susceptibility within the range from 30×10^{-5} to 50×10^{-5} indicates an increased content of anthropogenic ferromagnets. Magnetic susceptibility from 50×10^{-5} to 100×10^{-5} is regarded as high, and above100×10^{-5} as very high. The average Polish magnetic susceptibility for forest soils is defined on the basis of the Map of Magnetic Susceptibility of Soils of Poland and equals to 22×10^{-5}.

Investigations of the surface magnetic susceptibility of marshy areas soils showed an increased concentration of iron, while the share of other ferromagnets proved to be low. K values were contained within the range from 15×10^{-5} to 70×10^{-5}. The distribution of ferromagnets was correlated with the type of the investigated soils.

The investigations of the vertical magnetic susceptibility distribution proved that the maximum κ values generally did not exceed the value of 50×10^{-5}. The maximum of κ value was found at the depth of 4.0 to 10.0 cm in all of the investigated research plots.

As a result of the carried out chemical analyses the total value of congeners PCDDs and PCDFs in the investigated soil samples did not exceed the value of 8.0 ng PCDD/F- TEQ/kg. To compare the content of PCDDs and PCDFs in agriculturally utilized soils must not exceed 10 ng/kg, and for non-arable soils the value is 50 ng/kg.

Road bearing strength investigations

Synthetic results of forest road bearing strength investigations carried out on the area of the Lasy Rychtalskie Complex marshlands are gathered in Tab. 3. From among four investigated forest road on bog - basis best showed pavement with broken trick / concrete broken stone. The surface met the criteria of bearing strength for forests roads with traffic load of KR – 1 $E_1 > 100$ MPa. It must be noticed though that the bearing strength (E_1 = 104.6 Mpa) was reached in dry conditions, when groundwater level decreased to below 180 cm. The same surface lost up to 60 % of its bearing strength in the situation of groundwater table increase by 110 cm.

In the Mariak forest range the roads with slag pavement were situated in the areas where ground waters were shallow i.e. 33 to 45 cm below ground level.

Table 3. Reformation modules of forest roads pavements for extremely deep groundwater levels in road subsoil

Location and type of pavement	Primary E_1 and secondary E_2 pressure value	Reformation modules in MPa and $I_o = E_2/E_1$			Terms of tests and groundwater level b.g.s.
		Range of primary pressures in MPa			
		0.05 – 0.15	0.15 – 0.25	0.25 – 0.35	
Marianka – broken trick/ concrete broken stone	E_1	91.8	78.9	104.6	August 2005 183 cm
	E_2	83.3	107.1	125.0	
	I_o	0.91	1.36	1.19	
	E_1	30.8	34.9	40.9	April 2006 73 cm
	E_2	51.7	62.5	72.6	
	I_o	1.68	1.79	1.77	
Marianka – dirt road	E_1	12.3	8.9	4.0	August 2005 182 cm
	E_2	17.2	18.0	6.7	
	I_o	1.40	2.03	1.66	
	E_1	5.9	6.7	2.1	April 2006 61 cm
	E_2	4.2	-	-	
	I_o	0.71	-	-	
Mariak – melafire broken stone	E_1	46.4	43.7	31.5	August 2005 38 cm
	E_2	48.9	70.3	80.4	
	I_o	1.05	1.61	2.55	
	E_1	24.9	30.6	36.0	April 2006 33 cm
	E_2	54.2	69.2	73.8	
	I_o	2.18	2.26	2.05	
Mariak – slag	E_1	84.9	67.2	54.9	August 2005 45 cm
	E_2	84.9	100.0	166.7	
	I_o	1.00	1.49	3.04	
	E_1	48.9	54.2	43.7	April 2006 33 cm
	E_2	69.2	70.3	67.2	
	I_o	1.41	1.30	1.54	

Both pavements reached the strength meeting the bordering requirements set for road foundation and improved subsoil. Increased bearing strength can be achieved by lowering the groundwater level within the road frame. The changes will influence a decrease of water level in the neighbouring forest stand, which will have an impact on decreasing the area of protected marshes. And thus the solutions for an improvement of marshlands roads bearing strength should be searched for in the areas of various types of pavement construction and road subsoil reinforcements. Geosynthetics provide for obtaining good results in the construction of pavements [Kamiński, Czerniak 2003, Czerniak, Kamiński 2003].

SUMMING UP AND CONCLUSIONS

The annual outflow from the investigated marshlands is relatively low at 4% of the annual precipitation sum. Watercourses periodically take water away, mainly in the winter half-year. No typical storm flows were observed; only increased precipitation-thaw or subsurface or ground- fed rain outflows were recorded. Modelling the outflows from the areas, especially storm flow type one is significantly restricted by difficulties to evaluate the effective precipitation.

Water deficit which will occur in a relatively close future is the main threat to the ecosystems of the Lasy Rychtalskie Complex. It will take about 100 years for degradation of marshlands.

The carried out chemical investigations did not show an excessive cumulation of chemical pollutants in soils, as well as surface and ground waters of the Complex.

Dirt roads situated on marshy subsoil did not meet the conditions of bearing strength ascribed to forest roads. The strength of hard not improved roads depended mostly on the groundwater table level in the subsoil.

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