Technique of establishing water conservation zones for ranges of upper marshes based on remote sensing data and ERDAS IMAGINE

A.G. Gendrin, G.G. Rumyantseva, V.P. Kolmogorov,* Yu.P. Mylnikov, M.P. Shchegolikhina,* and S.V. Kvashnina*

Tomsk Petroleum Institute
** "Neftestroiizyskaniya, Ltd.", Tomsk*

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In this paper, the methodical approaches based on remote sensing data interpretation aimed at determination of hydrological properties of the marshland micro-landscapes is shown to be applicable for the operation territory of JSC "Tomskneft VNK." Topographic interpretation of satellite and airphotos of marshlands enables one to isolate micro-landscapes with similar variability of the flowage modulus along any sink line. Those micro-landscapes serve collector zones for the marsh water drainage (sedge–Hypnum, Hypnum–sedge, moss–grass, heavily watered hollow–ridge, and lake–ridge micro-landscapes). A water conservation zone can be set starting from the boundary of the above-mentioned micro-landscapes and into the adjacent dry territory in accordance with a regulatory document in force.

At the present-day technologic level of oil-gas field construction and maintenance, determination of water conservation zones (WCZ) and riparian shelterbelts (RSB) of surface-water bodies is now among the most important actions of the regional policy of environmentalism. As to Western Siberia, the problem of WCZ determination in marshlands is of a particular concern.

Russian Federation Government decree No. 1404 of November 23, 1996 is the basic document[1] for WCZ determination. According to this decree, determination of minimum widths of water conservation zones of waterways and lakes is clearly regimented and does not involve difficulties in the engineer designing. Nevertheless, WCZ determination for marshlands is quite difficult because of the absence of recommendations for Western Siberia.

The lack of the methodological instructions makes it difficult to develop WCZ projects and preparation of project documents for oil- and gas-fields construction.

Hydrological characterization of the marshlands has been performed based on data of satellite and airphotos interpretation and of the engineering–ecological surveys conducted by Tomsk Petroleum Institute in 2001–2004, as well as on the results of hydrologic investigations conducted by the West-Siberian expedition of the State Hydrological Institute (SHI).[2–6] Today, the satellite and airphotos interpretation is widely used in different areas. For example, on-line satellite forest monitoring is carried out using space-based optoelectronic devices and multi-channel image processing software for Earth surface, which is designed and successfully used both at the federal and regional levels.[7,8]

Interpretation of satellite and airphotos consists in using direct and indirect decoding signs to define structure of marshlands and micro-landscapes, their physical and hydrological properties. It enables one to distinguish a bog micro-landscape territory; identify the type of a marsh range; types, boundaries, and regularities of micro-landscapes allocation; determine boundaries of intrabog drainages, character and size of their elements; as well as the swamp water outflow directions. A typological map and a waterway net are the result of this work. The waterway net shows directions of surface and seepage waters within the marsh ranges. Methods, decoding signs (direct and indirect), net construction techniques, and fields of the net application to hydrological research were developed by K.E. Ivanov.[3–5]

K.E. Ivanov isolates three stages[5] in the evolution of marsh ranges, which are of the basic importance for analysis and calculation of the marshland hydrology.

At *the first stage*, the water influx balance of a marshland system is made by three constituents, namely, by precipitations on the surface, waters from surrounding aquifers, and surface water runoff from the surrounding uplands.

At *the second stage*, the constituents can be the same, but the distribution of water from different sources over the marsh territory differs. Marsh replenishment is nonuniform by water chemistry and salinity in its different parts, which results in differentiation and heterogeneity of the vegetation cover.

At *the third stage*, due to positive relief, participation of surface and nonartesian subsoil waters is either totally excluded from the marsh water supply or it is restricted by a narrow near boundary band between the marshy peat bed and mineral soils.

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At this stage, moor vegetation can be the most differentiated: from eutrophic to oligotrophic.

The considered stages, basic in the development of a separate marsh range, characterize periods of changes in the marsh relief and its water supply conditions. Within each stage, successive stages of the marsh range evolution are distinguished depending on territorial distribution of primitive plant aggregations and landforms.

In natural marshlands, two horizons are isolated, which differ in hydrophysical parameters: upper active and lower inert ones.

The active horizon water capacity of undrained marsh range is thousands and dozens of thousands times higher than the filtration coefficient of peat beds which form the inert horizon. The filtration coefficient in the active horizon varies from $a \cdot 10^{-2}$ to $a \cdot 10^{2}$, where a is a positive number between 1 and 10.

According to definitions of the marshy micro-landscapes (or facies) and active horizon,[3–5] physical properties of the active horizon are invariable within a particular micro-landscape. Hence, the following parameters are constant within some individual marsh range: horizon thickness; average filtration coefficient of a filter-bed; unit horizontal discharge at a definite ground-water level; water chemistry; distribution function of the filtration coefficient in the active layer; dependence of water yields on a swamp waters' level, modulus of flowage. The set of constant values of the above parameters is a hydrological characteristic of a marshy micro-landscape.[5] In its turn, this characteristic must reflect properties of a group of related marshy micro-landscapes. In the most general form, the hydrological characteristic of a marsh range is a totality of dependences of the modulus of flowage on discharge line parameters all over the marshy territory, since values of the modulus of flowage in horizontal and vertical directions characterize intensity of water exchange at a particular point of the marsh range and have comparable physical parameters for different marshy micro-landscape types.[5]

The specificity of vegetation cover determines differences, which are well seen in images taken from space. When decoding, the color synthesis of the 3rd, 4th, and 5th channels corresponding to the red, visible, and near-infrared spectral ranges were used. These channels are most informative in vegetation decoding, because they correspond to maximum spectral brightness of the vegetation cover (0.63–1.75 μm). In addition, the information from the near IR range allows identification of different bog types. Based on interpretation of summer space images taken from the Landsat-7 satellite, bog micro-landscapes with similar variation of the modulus of flowage can be distinguished.

Images were processed in ERDAS IMAGINE 8.6 system. As the ground-based references, the field data of bog inspections were used. Based on these data, 5 independent sets of the upper marshes micro-landscape standards were created. The quality of the standards was estimated using histograms and plots of the spectral brightness mean values (Fig. 1). Image classification by the standards was conducted following the principle of maximum likelihood as a parametrically decisive law.

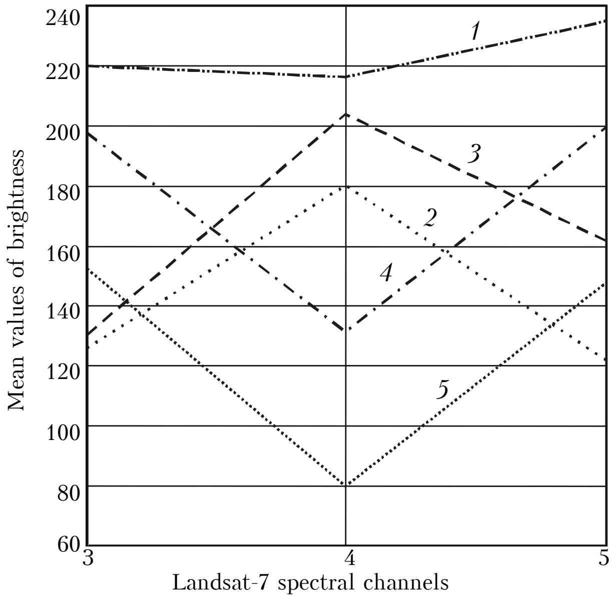


Fig. 1. Divide diagram of upper marshes micro-landscapes in 3rd, 4th, and 5th spectral channels of Landsat-7: moss–grass (sphagnum–sedge–cotton-grass) (*1*); pine–bush (*2*); pine–sphagnum–bush (*3*); ridge–hollow (less watered) (*4*); heavily watered ridge–hollow (*5*).

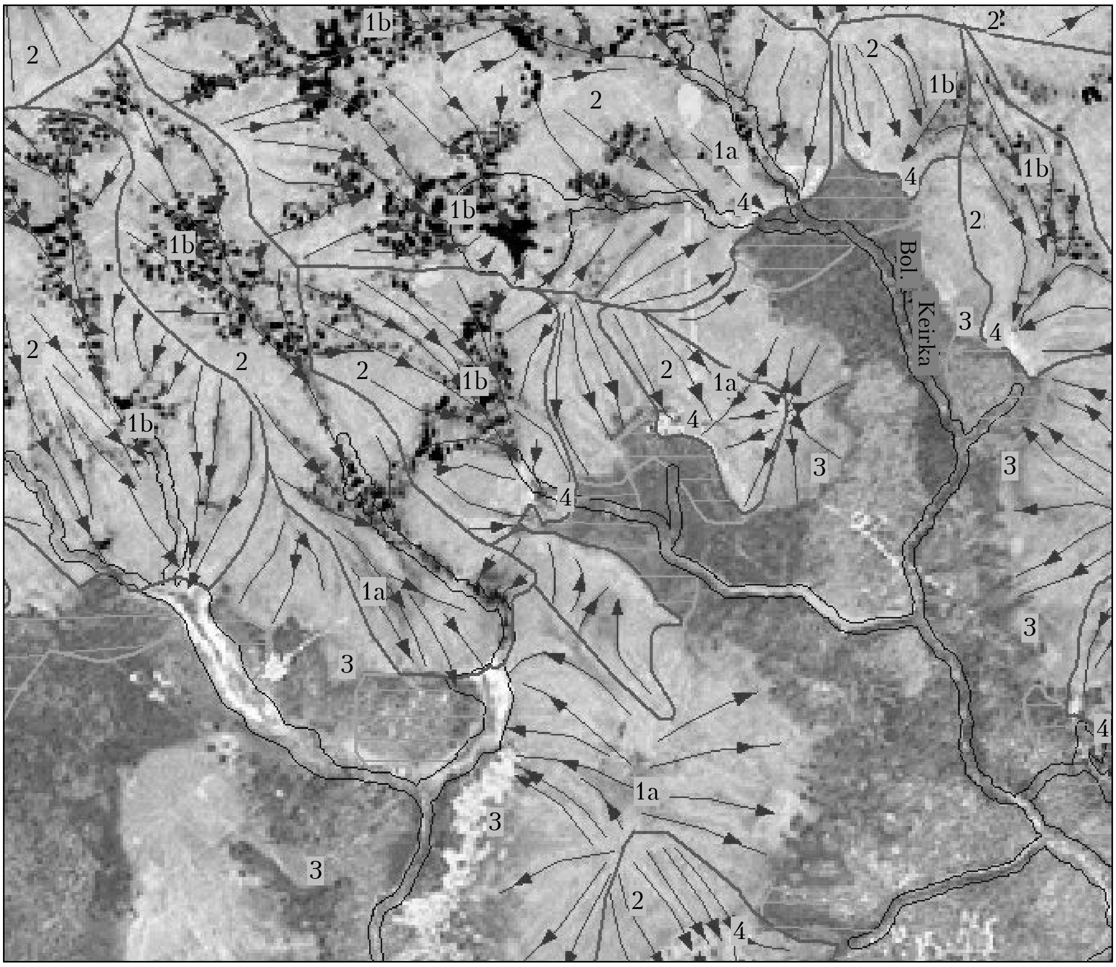
The decoding of the satellite and airphotos allows the separation to be made within the marshy landscapes of micro-landscapes with similar variation of flowage modulus along any sink line. A satellite photograph of Dvurechensk deposit territory with marked shapes of local watersheds, micro-landscapes, and sink lines is shown in Fig. 2. Hydrologic characteristics of most typical bog micro-landscapes within marshy watersheds of the Tomsk Region[3,5] are presented, according to K.E. Ivanov by the following values of the modulus of flowage and bog surface slopes:

1a. Ridge–hollow with sphagnum–bush, pine-forested ridges; sphagnum–scheuchzeria and sphagnum–cotton–grass hollows, with a modulus of flowage of 2.7–15 cm^2/s; a many-year-mean flowage of 0.8–3.0 l/(s·km); and a surface slope of 0.0018–0.0035.

1b. Heavily watered ridge–hollow, ridge–lakelet with sphagnum–bush, and sphagnum–bush–cotton-grass with not forested or thin-forested ridges, and sphagnum–scheuchzeria hollows, with partly open surface, or lakes; with a modulus of flowage of 140–170 cm^2/s; a many-year-mean flowage of 11–15 l/(s·km); and surface slope of 0.0008–0.001.

2. Pine–sphagnum–bush (a forest height of 4–6 m), sphagnum–bush, and sphagnum–bush–cotton-grass pine-forested with a modulus of flowage of 1.4–2.5 cm^2/s; a many-year mean flowage of 0.7–2.0 l/(s · km); and a surface slope of 0.00125–0.008.

3. Pine–bush (a forest height of 9–13 m) with a modulus of flowage of 0.5–0.7 cm^2/s; many-year-mean flowage of 0.5–1.5 l/(s·km); and surface slope of 0.01–0.02.



Upper marshes micro-landscapes:
ridge–hollow (less watered) (1a); heavily watered ridge–hollow and ridge–lakelet (1b);
pine–sphagnum–bush (forest height of 4–6 m), sphagnum–bush (2);
pine–bush (forest height of 9–13 m) (3); sedge–Hypnum, Hypnum–sedge and moss-grass (4).

Other marks:
local watershed area boundary; sink line;
WCZ of upper marsh; WCZ of water ways, lakes

Fig. 2. Image of Dvurechensk deposit taken from satellite.

4. Sedge–Hypnum, Hypnum–sedge, and moss–grass with a modulus of flowage of 170–240 cm^2/s; many-year-mean flowage of 5–9 $l/(s \cdot km)$; and surface slope of 0.0001–0.0005.

Analysis of hydrologic characteristics of micro-landscapes, interpretation of satellite and airphotos, and ground observations[3–5,9] allows the identification to be made of micro-landscapes with local concentration of bog-water discharges, which then come to primary drainage (brooks, rivers).

Analysis of observations of marsh ranges typical for zone of relief oligotrophic peat of divide-slope bedding and including both upper ridge–hollow micro-landscapes and lowland marshes[4] shows that the discharge from the upper marshes ranges follows the water level in marshes and in summer–fall periods it stops for a long time at the following water level at the moments of discharge cessation and restart: from –32 to –38 cm (–40 cm by data from Ref. 9) from the surface of lowering in a sphagnum–bush, pine forested micro-landscape. However, a zero minimum discharge in summer and winter periods does not occur every year. A through-year discharge was observed in situations, when the precipitation amount was high and the ground water level did not reach the bottom level of the active horizon.

Thus, the observational data show[4,9]:

1. The sink from natural marshlands continues as long as the ground water horizon is within the active layer of marsh waters.

2. The elements of the primary drainage (brooks, rivers) are the water-receivers of the marsh water sink. Surface sink in brooks and rivers is formed owing to the sink concentration in micro-landscapes with maximum modulus of flowage – flowing swamps, boundary swamp hollows (sedge–Hypnum, Hypnum–

sedge, and moss–grass micro-landscapes), heavily watered ridge–hollow and ridge–lakelet micro-landscapes. According to Ref. 6, more than 50% sink of marsh waters are due to the primary drainage.

3. Sink from less watered (a modulus of flowage of 2.7...15 cm^2/s) pine–sphagnum–bush, sphagnum–bush, and sphagnum–bush–cotton-grass (pine forested), pine–bush micro-landscapes comes as filtration flows to surrounding territories, and then via infiltration – to the soil water.

4. Around the marshland periphery, a zone of melting water accumulation is separated out, which is a band of marshy forests, where water is formed due to melting of the local snow cover and income of thawed snow from bogs. In this zone, a channel sink (drain) is formed in the band of the primary drainage and a soil water spreading takes place.

5. Long periods free of sink in summer and winter months are characteristic of the marshlands. During these periods, a stable river replenishment by water is broken. The presence of marsh ranges in a river catchment area does not favor the regularity of the river run-off.

6. The upper marshes transform only atmospheric precipitation water, that is, only one type of conditions for the slope sink.

The regularities of formation of sinks from marshes, determined in the course of the stationary and expedition observations, allow a sufficiently reliable estimation to be obtained of the water-exchange in the waterlogged catchment areas of rivers.

Divide marshes are most abundant in the relief oligotrophic bog zones, individual parts of which are situated on the territory of two (or more) different complex river basins. This can be demonstrated with estimate of hydrologic components for a watershed having the following parameters: the marshy area occupies 43%, the water-logged land area – 26%, and area of the land free of marshes – 31% (Ref. 5).

Based on the supposition that all annual mean variations of water reserves for many years tend to zero, the following values of the components of the year hydrology for water-logged catchment area with marsh ranges of divide type were obtained (on the average, for 6 observational years):

– precipitations of 711 mm, evaporation of 498 mm, sink of 244 mm;

– surface (horizontal) sink from marsh ranges is 186 mm; its significant portion is concentrated in micro-landscapes with maximum modulus of flowage in spring period (the water exchange is very low during other seasons)

– on the whole, for 6 years the drain was replenished with ground waters insignificantly, 31 mm on the average.

Thus, taking into account the above conclusions on peculiarities of drains from marsh ranges and marshy inland water reservoirs, the following procedure of setting water conservation zones seems to be reasonable in the framework of the Government decree No. 1404.

– Water objects – upper marshes, forming a sink in some river catchment areas, are determined in accordance with Ref. 1.

– Based on data of interpretation of satellite and airphotos, the fragments of marsh ranges are determined: micro-landscapes with maximum values of flowage modulus, within which a bog outflow is concentrated and a surface drain is formed in the primary hydrographic basin (sedge–Hypnum, Hypnum–sedge, and moss–grass landscapes, as well as heavily watered ridge–hollow and ridge–lakelet ones).

– The water conservation zone is set beginning from the boundary of the sedge–Hypnum, Hypnum–sedge, and moss–grass micro-landscapes into the adjacent dry-land territory[1] as for lakes (depending on the local catchment area of the watered micro-landscapes).

– The water conservation zone is set beginning from the boundary of heavily watered ridge–hollow and ridge–lakelet micro-landscapes into the adjacent dry-land territory[1] as for lakes (depending on the local catchment area of the heavily watered ridge-hollow and ridge–lakelet micro-landscapes).

– Use of space data without atmospheric correction to solving the formulated problems is reasonable only in cases when the atmosphere can be treated transparent. The control for the atmospheric state can be performed with the MODIS AEROSOL PRODACTS (MOD04) programs.

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