Derivation of mine waters under conditions of spotty permafrost (Yun-Yaga deposit)

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ABSTRACT: A detailed description of the hydrology around the Yun-Yaga coal deposit is presented, with especial attention to mine flooding and drainage and the consequent changes in ground water levels, development of sizeable cones of depression, etc. It has been determined that much of the flood water comes from lakes and streams, but some of it is at the expense of ground-water reserves. In some parts of the basin, the principal source is direct infiltration of rain water. Spotty permafrost in the area complicates matters and the water yield depends in part on the position of a shaft with respect to boundaries of the permafrost areas. Some of the pumped water drains back into the mines. It is concluded that the flooding could be prevented, or drastically reduced, by control and diversion of surface drainage. This would involve lining stream channels and diversion and drainage ditches with impervious material.--E. Ingerson.

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The hydrogeology of coal mining in the northeastern Pechora Basin, as well as the replenishment of underground waters, their connection with surface waters, distribution and interrelationship of the aquifer horizons, and a number of related problems, have not been adequately discussed in the literature. The authors have studied in detail the conditions and extent of flooding in the Yun-Yaga mineral deposit, prior to sinking the shaft and during the early production period. The data so obtained help refine our concepts of the hydrogeology of larger deposits of the basin, with similar natural conditions -- namely of the formation of underground waters which flood mining works in the zone of spotty permafrost. The problem of underground water replenishment in the northeastern part of the Pechora Basin - a region of extensive permafrost development - is quite complex.

At an early stage of coal mining in this basin, most investigators were inclined to look to the Polar Ural foothills and Chernov Uplift for sources of underground waters and their pressure head (Gordiyenko, 1944). K.G. Voynovskiy-Kriger, G.M. Yaroslavtsev and others suggested the possibility of a limited seepage of surface waters, directly in the areas of the coal deposits.

Later on, I.A. Gabovich (1956) and other investigators arrived at the concept of a mixed mode of replenishment for underground waters of this region, i.e. not only by distant waters but to some extent also by those from local sources. Detailed geologic exploration was carried out in 1959 in Hydrogeologic Section No. 4, in the Vorkuta - Yun-Yaga watershed. On the basis of this material, I.A. Konzhin and V.A. Kal'm (1965) demonstrate that the underground waters are replenished from the surface by seepage directly in the area of the deposit; they advance the hypothesis of a preferentially local replenishment of underground waters in regions of spotty permafrost. S. Ye. Sukhodol'skiy (1960), also, cites a number of convincing arguments for local sources of underground waters. As a result of further study in the northwestern part of the Basin, by the Vorkuta Geological Exploration Expedition and the Northern Division of the Permafrost Institute, extensive development of thaws has been demonstrated within the permafrost; also a direct relationship between the underground and surface waters, and the considerable effect of the latter on water flow in both the newly-driven and operating shafts. The Yun-Yaga coking coal deposit is typical in that respect.

This deposit is situated in a depression of the Usa-Vorkuta watershed, with absolute elevations of 150-200 m. The depression is swampy and covered by peat bog; it shows numerous thermokarst funnels, mostly filled with water.

The main draining stream is the Yun Yaga, crossing the southeastern part of the deposit area. Its valley is poorly defined. The sinuous river channel presents a chain of lake-like elongated open stretches separated by shallows 20-70 m long and 3-5 m wide. The moving stream is 0.2-0.5 m deep in the shallows and 1.0-1.2 m in the open reaches. Its discharge is 200-430 m^3/hr in summer, rising to 2,500 m^3/hr in the period of autumn rains. The flow almost ceases in the winter, but in flood may be as high as 10,000-14,000 m^3/hr.

Permian rocks of the Yun-Yaga deposit form a small, narrow asymmetrical anticline with the north flank steeper (35-50°) than the south

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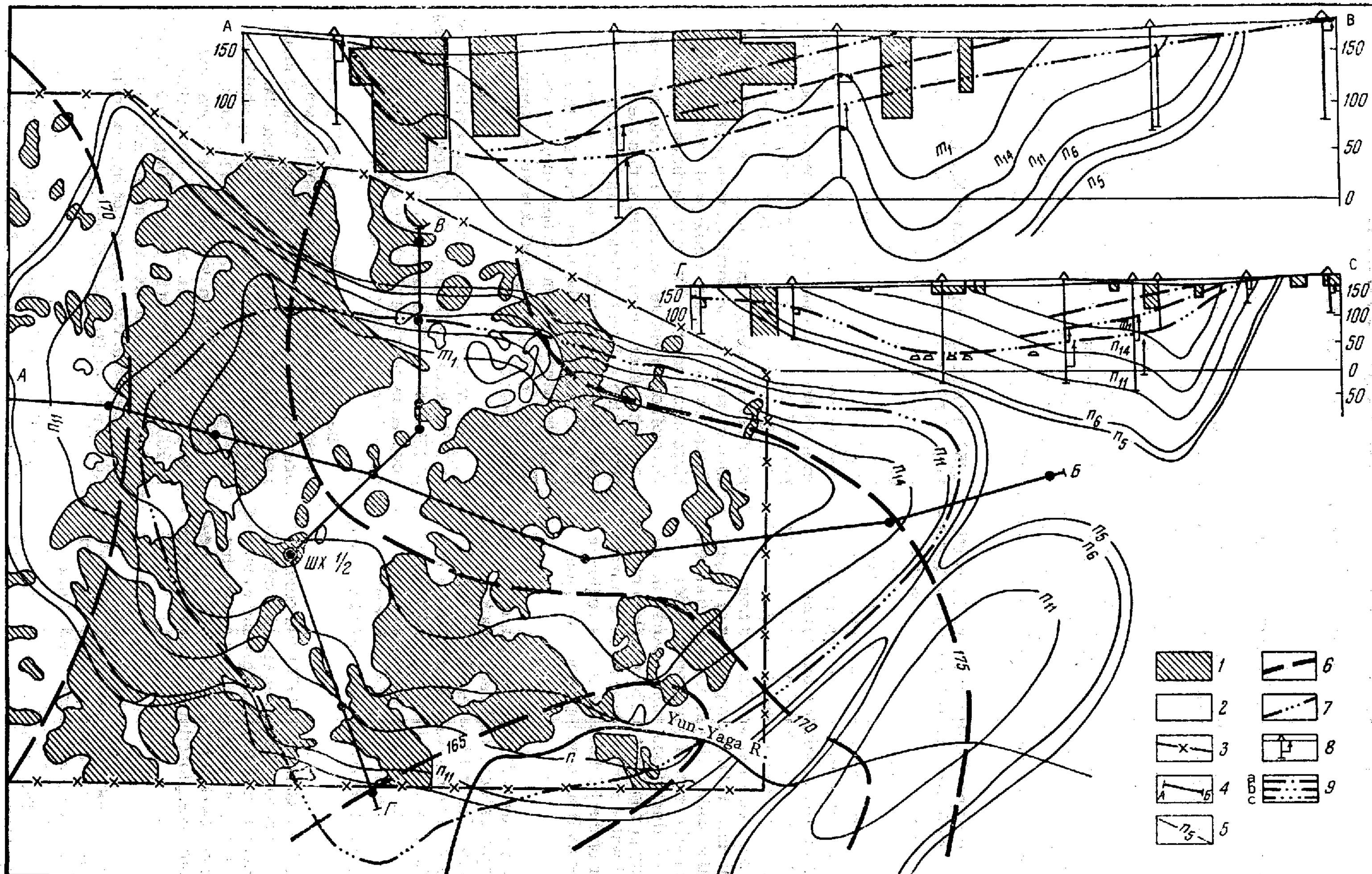

FIGURE 1. Schematic hydrogeologic map of Yun-Yaga coal deposit

1 - areas of permafrost development; 2 - areas of thaws through the entire frozen interval; 3 - boundaries of the area of hydrogeologic survey; 4 - cross-section lines; 5 - coal seams; 6 - contours on water table prior to coal mining; 7 - outline of the depression cone formed by the shaft drainage; 8 - underground water pressure head in the aquifers;
9 - water level surface in the aquifers: a) top of layer m_1 b) top of layer n_{14}; c) top of layer n_{11}.

(8-18°). Adjacent to it in the east is an auxiliary synclinal fold separated from the principal one by an anticlinal flexure. No large disjunctive disturbances have been identified by the exploration and mining works. The main fold is complicated by six second-order transverse folds; these in turn are complicated by microfolds. The folding tectonics has produced intensive fracturing in the Permian rocks. The several systems of fractures dip at different angles and some are parallel to the bedding. Fracture spacing (up to 10 per meter) is closest in the very fine clastic rocks (argillites). The sandstone beds are broken up by occasional larger fractures, with fracturing most intensive in zones of secondary folding. The Permian coal measures are represented by sandstones (40%), siltstones (34%), argillites (21%), and coals (5%). Four out of the nine coal seams of the Rudnitsa sub-suite are slated for production: Layers n_{14}, n_{11}, n_6, and n_5; their average thickness is 0.9-1.8 m. The Permian rocks are buried by Quaternary boulder loams and sandy loams with stringers of sands and gravel-pebble formations. Their thickness varies from 0.5-2.0 m at the edge of the deposit to 30-40 m in the northwest, where the bedrocks form a depression. Over most of the area, the Quaternary deposits are 5-10 m thick.

Unlike other coal deposits in the north of the Pechora Basin, where the thaws are less common, over 50% of the Yun-Yaga deposit area lies within the zone of thaws affecting the entire permafrost interval. The latter varies here from 10 to 18 m (fig. 1). The thaws are more extensively developed beyond the commercial coal area. As demonstrated by geocryologic mapping carried out by the staff of the Northern Division of the Permafrost Institute, permafrost is developed in western and eastern parts of the deposit. Its depth varies greatly over short distances. It is thickest in depressions under the peat bogs (an area of 300 x 500 m; thickness, 0.2-4.5 m). Continuity of the frozen bodies is broken up by the thaws and pseudo-thaws associated with the thermokarst lakes and swampy hollows, up to 100-150 m in diameter. Depth to permafrost in the areas of pseudo-thaws varies from 4-6 to 30-40 m. In some thermokarst hollows, the frozen body consists of two layers, with a total thickness of 60-100 m and at times over 150 m. Permafrost is absent beneath the Yun-Yaga valley, as it is underneath other rivers of the region.

Within this and the adjacent area, the frozen zone has a moderately low temperature (minus 1.0-2.5° C).

The isolated hydrogeologic area of the Yun-Yaga deposit is bounded on the north, east, and south by contacts between the Lower Permian deposits and Carboniferous limestones; on the west, by the axis of an anticline in rocks of the Ayach'yaga subsuite. Here the area of underground drainage is 50 km^2. Under natural conditions the underground flow is from northwest to southeast, toward the Usa river. The considerable flooding of the deposit is determined by conditions favoring seepage of rain water (small thickness of the Quaternary deposits; nature of relief controlling surface drainage; wide distribution of thaws; intensive fracturing in all lithologic varieties of the Permian rocks). The principal Permian aquifers are represented by thick sandstones and to a smaller extent by Ayach'yaga siltstones above the coal seams and outside the productive area. Unlike that of other coal deposits of the Basin, fracturing in Yun-Yaga does not decrease with depth (within the workable area) because of the tectonics of the area; the same is true for flooding. Underground waters are of the fracture and bedding-fracture type here.

The Ayach'yaga sub-suite deposits are characterized by a moderate water yield. A pumping station is being built 5 km west of the deposit, in the thoroughly explored Section No. 4, to supply water for the city of Vorkuta. Production rate for the wells is 3.8 liters/sec, with one well flowing at 15 liters/sec. There is a vertical hydrochemical zonation in this deposit, as elsewhere throughout the Pechora Basin. Calcium bicarbonate waters circulate in the upper aquifers, down to absolute elevations of minus 150-170 m; here they are replaced by sodium bicarbonate waters and then (below minus 280-300 m) by sodium chloride. Prior to mining work, static levels of underground waters in bedrock aquifers penetrated by drilling, at different depths, stood at about the same absolute elevations near the surface. Water movement without a pressure head was observed in those areas of intensive seepage of rain water associated with the thaws (especially in the upper interval of the Permian section); more often, the underground waters had a local pressure head.

In the north of the Yun-Yaga structure, where the beds dip at steep angles, underground water movement is impeded by the low-permeability argillites. A fairly thick layer of permafrost is extensively developed in the west; in addition, the sandstones are replaced by siltstone and argillite facies, all of which lowers the rate of surface-water seepage and interferes with underground water circulation through the bedrocks. Developed in the east and south parts of the deposit are thick gently dipping sandstones. Here the prevailing conditions are most favorable for underground water movement.

At an early stage of shaft construction, water flow increased from 2 to 30-40 m^3/hr, as deeper horizons were penetrated, especially the sandstones. When a thick sandstone horizon above the n_{11} seam was opened, the flow increased to 159 m^3/hr, because of the strong pressure head in the fractures (flows in other Vorkuta area shafts did not exceed 50-100 m^3/hr). Flows from aquifers above the n_{14} were 25-30 m^3/hr.

Underground water yield in the preliminary shaft work depended mostly on the shaft position with respect to the boundary of the permafrost area; also on the lithology and fracturing of the penetrated rocks. For instance, flow rate in the west section inclines, within the thaw zone, was 60 m^3/hr, while the east section inclines, within the permafrost zone, were virtually dry.

Total yield of water from below the permafrost zone, in the eastern inclines, was 150 m^3/hr. A small discharge was observed in inclines driven in the horizon n_{13}, in the crest of a second-order anticlinal fold. Flooding of the shaft yard and hauling horizon at 140 m, in the most flooded bedrock interval, likewise depended on the lithology and tectonics of the section area. The flooding streams had different pressure heads, with flow rates not exceeding 100 m^3/hr. For instance, when the hauling cross-cut of Horizon I intersected sandstones above n_{11}, water flowed in at a rate up to 250 m^3/hr; the stabilized flow into the cross-cut was 200 m^3/hr. Up to 250-290 m^3/hr entered the principal works of the mine yard. A steady rise in total incoming water was noted during the shaft construction, the overall figure being as high as 720 m^3/hr (fig. 2). The seasonal changes were expressed in higher flows (by 25-90 m^3/hr) during the spring floods and especially during the autumn rains.

Dynamics of water flow into shafts of the Vorkuta deposit, under similar geologic conditions, is as follows. During the preliminary work and early production, water flow into the mining works increased because of the greater length of the latter within the working area. Subsequently, any increase in water flow because of expanded mining was compensated for by a lower discharge in the yard segment and in places where the mines were not worked following the clean-up job. Mine flooding was stabilized at that period and even decreased somewhat as the underlying horizons were worked out. Water flow in the Vorkuta deposit mines does not exceed 100-150 m^3/hr. An exception is the flow in the mines in the immediate vicinity of the Vorkuta river, where the flow rate reaches 250-300 m^3/hr (as for instance in Nos. 8 and 40). Figure 2 presents the water discharge curve for Yun-Yaga mine during its construction period; presented for comparison are discharge curves for two Vorkuta area mines.

As the result of mine drainage, hydrogeologic conditions of the deposits underwent a marked change. Depression cones characterized by

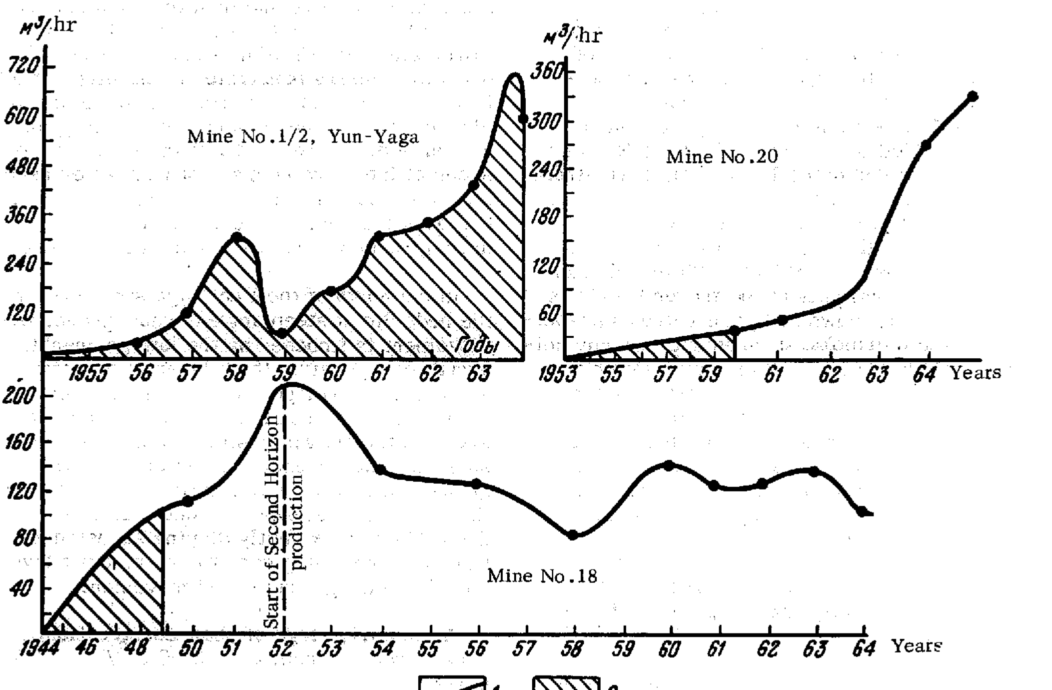

FIGURE 2. Water discharge in Yun-Yaga mine and Vorkuta mines Nos. 18 and 20

1 - Curves of mean annual flow to the mines   2 - Flow during mine construction.

definite positions of the piezometric levels were formed in all more or less consistent aquifers associated with sandstones, 8-26 m thick, above the seams n_1, n_{14}, n_{11}, n_6, and n_5. At present these depression cones in the north and west of the deposit approach the producing area outlines, and their steep sides rise to the original water-level surface. In the south, the underground water level surface depression extends beyond the deposit and takes in a considerable stretch of the Yun-Yaga river.

Going east, the depression cones reach the edge of the productive area (fig. 1). The greatest depression of the water level takes place in a sandstone bed above the seam n_{11} and those overlying it. Judging from the drilling and mining data, this aquifer has been completely drained in the mine yard area, to the absolute elevation of + 40 m (at a depth of 130 m), while its level surface 600 and 1,000 m away from the mine shaft has been depressed by 115 and 105 m, respectively. The water level of two overlying aquifers, at the same distances, has been depressed by 65-35 m, in the first, and by 85-65 m in the second (fig. 1). The marked difference in position of the underground water levels for the most flooded sandstone beds indicates a degree of isolation for the latter; the implication is that these beds are aquifers to some extent in their own right, with but a restricted connection between them.

As the result of its marked lowering, the level of underground waters fell 28 m below the channel and sub-channel flows of the Yun-Yaga, within the productive area. Over a distance of 1,800 m this stream, formerly draining the underground waters, now becomes the source of their supply. Also situated above underground waters of the deposit are surface waters of lakes, creeks and mine drainage canals. Under such conditions, mine flooding waters come from a) seepage from the surface streams and reservoirs; b) rain water seepage directly within the depression cone and over the entire area of underground drainage in the direction of the deposit; and c) static resources of underground waters within the area of mine drainage.

Hydrometric observations show that seepage from the Yun-Yaga river, over a distance of 1,800 m, is 100-400 m^3/hr, depending on its seasonal discharge, about 150 m^3/hr on the average. River water infiltration rises (in proportion to its discharge) up to 400 m^3/hr. A further increase in river discharge has hardly any effect on the seepage rate. In the summer, surface flow ceases in some stretches of the river, and there is only the seepage of the Quaternary and bedrock (the alluvium, mostly sandy, varies in thickness from 0.7 to 5 m).

It has been established by special hydrometric and experimental studies that some of the mine water (dumped in the immediate vicinity of the working area) again replenishes the underground water resources, because of the favorable seepage conditions and again participates in mine flooding. As shown by subsurface hydrogeologic surveying, waters of two streams flowing in the southwestern part of the deposit seep through and also participate in mine flooding.

From rough computations, as much as 100-150 m^3/hr flows to the mines through all these channels. It appears that some water must seep through from lakes situated in the thaw areas. Thus, at the present time, almost 50% of the mine water comes from surface streams and reservoirs, by seepage within the depression cone area.

Water regimen data for the deposit, obtained since 1963, show that as the mine works expand, the water level surface is steadily depressed; in other words, the reserve of underground water is gradually exhausted. For this reason it is more correct to assume that mine flooding is accounted for in part by a reduction in the reserve of underground waters as well as by an infiltration of surface water over the entire area of underground drainage in the direction of the deposit.

The volume of water coming into the mine works, at the expense of the reserve, can be calculated with the P. P. Klement'yev formula (1953):

$$W = \mu \cdot V$$

Here, V is the volume of the aquifer horizon, taken as the entire volume of drained rocks within the drainage zone, with the average level depression for underground waters at 80 m, over the depression cone area of 10 km^2. The water yield $\mu = 0.003\text{-}0.005$ was computed by the Bindeman method (1964), for the entire upper interval of the Permian section. Reserves of underground waters drained by the mine during the construction period (9 yr) were 2.4-4.0 million m^3. Taking an average of 3.5 million m^3 for the original reserve, and distributing this volume over the nine years of drainage, we obtain a tentative figure of mine flooding at the expense of these resources, of 50 m^3/hr.

The rate of exhaustion of the reserve can be described by the rate of water level lowering for the principal aquifer horizons. For instance, the water level in boreholes to the sandstone aquifer above the seam m_1 fell by an average of 4 m, in February and March of 1964, and by 3 m in sandstones above the seams n_{14} and n_{11}.

If we compute the volume of the drained portion of these layers and assume the sandstone water yield of 0.01, mine flooding at the expense of reserves, for the two months of most intensive drainage, is at the rate of 59 m^3/hr. This supports the relative accuracy of the original calculation of water flow.

Water levels in the aquifers ceased to fall beginning in the spring of 1965 because of some reduction in mine drainage. Water level rose in all boreholes; this means that present reserves of ground water of the area are increasing slightly in spite of continued drainage. In order to determine the magnitude of seepage of rain water under natural conditions of the deposit, underground drainage was tentatively calculated for a unit of surface in the Yun-Yaga upper basin (assuming that seepage of surface water, averaged for many years, equals the underground drainage). The underground drainage modulus, 1.5 liters/sec/1 km^2 under natural conditions of the Yun-Yaga deposit (outside the mine drainage depression cone), compares well with moduli previously computed for the Vorkuta and Bol'shaya Inta basins (Konzhin and Kal'm, 1965). In the Vorkuta Basin, where the thaws are not as common as in the Yun-Yaga Basin, the underground drainage modulus is 1.6 liters/sec/1 km^2. These data lend plausibility to the figure of 1.5 liters/sec/1km^2 for underground drainage (or ground-water replenishment) in the Yun-Yaga deposit. On this basis, seepage from the surface over a 50 km^2 watershed is 270 m^3/hr throughout the year. A portion of this seepage forms underground drainage of the Yun-Yaga river and other streams and is also expended in seepage to the aquifers within the mine drainage zone; another portion replenishes the resources of the same aquifers, directly in the watershed area. However, mean annual seepage from the river is up to 150 m^3/hr, while the underground drainage is only 120 m^3/hr; i.e. the river loses 30 m^3/hr in surface drainage. The same is true for the streams whose mean annual loss by seepage is up to 60 m^3/hr, with a surface drainage of 12 m^3/hr.

In 1964 the mines were flooded at an average rate of 580 m^3/hr: a) seepage from the watershed area (including losses by underground drainage from surface sources, in the mine drainage area) – 270 m^3/hr; b) losses by seepage from surface streams – 42 m^3/hr; c) losses from dumped mine waters – 100 m^3/hr; d) depletion of reserves of ground-water in the drainage zone – 50 m^3/hr. The total inflow was 462 m^3/hr, 118 m^3/hr less than the outflow (580 m^3/hr). The assumption then, is that seepage conditions in the depression cone zone are much more favorable than the natural. It has been calculated that the modulus of underground drainage (ground-water replenishment), under the conditions of intensive drainage for the aquifer horizons is 4.5 rather than 1.5 liters/sec/ 1 km^2.

Under such conditions, prevention of mine flooding must be effected by a control of surface drainage and by diverting the surface waters beyond the deposit area. In the instance of Yun-Yaga deposit, it is most important to eliminate surface drainage from high ground in the north, west, and east. Here it is expedient to run hillside contour drainage ditches beyond the coal seam outcrops. The ditch bottoms must be lined with impermeable material, to prevent seepage from the canals, because the latter would often be in fractured bedrock and permeable Quaternary deposits. Similar ditches must be used in diverting water from the largest lakes in the deposit area.

Seepage of the Yun-Yaga waters is more difficult to eliminate. Surface drainage to the valley, controlled by relief of the adjacent area, cannot be prevented by diverting the river channel beyond the deposit. It is more expedient to line with impermeable material the river channel and drainage ditches within the depression cone zone. Measures controlling surface water drainage would considerably reduce the total flow in the mines.

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It has been demonstrated in the instance of Yun-Yaga coal deposit, where 50% of mine-flooding waters is accounted for by seepage from the Yun-Yaga river, streams, and drainage ditches, that surface streams play an important part in flooding the mining areas in the northeastern part of the Pechora Basin – this despite the extensive development of permafrost. Supporting evidence was found for the earlier view that there is direct seepage of rain water in the area in question and to the south of it is the principal – and often the only – source of replenishing underground water resources. It can be conceded that infiltration of rain is much more intensive within the zone of aquifer drainage by mining works than under the natural conditions of ground-water occurrence, when the water level coincides with the water table and water surface of the lake and swamps.

At present, with active replenishment of ground-water known for the deposit, it is possible to control the flooding of mines and to select the most economical means of preventing it (surface drainage control; ground water control; melioration; and mine drainage).

An important discovery is that partial connection between the most highly aqueous Permian beds makes them aquifers in their own right, under the conditions of mine drainage; as such, they are characterized by different water yields, different pressure head drop, and different chemical composition of their waters.

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