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Systematic Processing of Iron-Ore Waste in Mining Regions

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Abstract—Management of the stepwise processing of iron-ore waste in mining regions ensures rational resource utilization by introducing waste-free and low-waste technologies, with subsequent conversion of the reclaimed land to recreation areas. A procedure that may be used by operational enterprises has been developed, including the sequence of operational steps, charts for tailings recovery and preparation of the equipment, and schedules. The steps run in parallel and include waste processing, recultivation, and the solicitation and selection of proposals for the creation of recreation areas. Waste processing and land reclamation proceed while the enterprise is in operation. The recreation areas go into operation after the enterprise has closed. Management of the stepwise processing of iron-ore waste at enterprises that have closed involves the development of funding sources for waste processing and land reclamation: this will include sale of the existing resources (buildings and equipment) and approaches to outside investors, including the state. With insufficient funding, some of the iron-ore waste may be used as construction materials or filler in the reclamation program. Management of the stepwise processing of iron-ore waste for ongoing projects includes periodic monitoring of the waste generation and damage to the ground cover. Existing technologies for waste utilization and recultivation of the affected land are applied. Periodic monitoring prevents environmental damage. Recreation areas are created while the enterprise is functioning, and go into use after it has closed. On the basis of these management procedures, proposals are made for the introduction of waste-free and low-waste technologies in the Tashtagol region of Kemerovo Oblast. Such technologies are simulated by means of SciLab software. For purposes of selection, the proposals are ranked.

Keywords: low-waste technology, waste-free technology, management procedures, mining regions, land reclamation, rational resource use, industrial waste, recreation areas

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In mining regions, the continuing growth of iron-ore wastes is creating social and environmental stresses [1–4]. In Russia, 53% of such wastes are processed [5]. That level falls far short of what is required to ensure rational resource and environmental management, upon which the health of future generations depends.

Most existing approaches to reducing environmental burdens focus on the limitation of emissions [6] and the introduction of uneconomical low-waste technology [7–10]. An integrated approach to waste processing, land reclamation, and the creation of recreation areas would be far superior [11–14]. Over the past few decades, environmental degradation in mining regions has impaired public health in comparison with national averages and fostered the emigration of the working population [15, 16].

A promising approach to improving the social and environmental conditions in industrial regions is the introduction of management procedures that ensure the utilization of production wastes, land reclamation, and the creation of recreation areas, with the reduction in overall pollution levels and the creation of new workplaces [17–19].

Thus, we need to develop management procedures for the stepwise processing of iron-ore waste in mining regions so as to reduce the environmental impact of mining enterprises and ensure rational resource utilization.

For operational enterprises, the management of the stepwise processing of iron-ore waste (Fig. 1) depends on the following:

—a sequence of operational steps and charts for tailings recovery (Table 1);

—preparation of the equipment and resources (selection of the equipment, materials, workforce, diagnostic instructions, etc.);

—schedules for waste processing, land reclamation, and the creation of recreation areas.

This procedure consists of the following steps. Proposals for the introduction of waste-free and low-waste technologies are assessed (step 1). If waste is present (step 2), the enterprise undertakes systematic

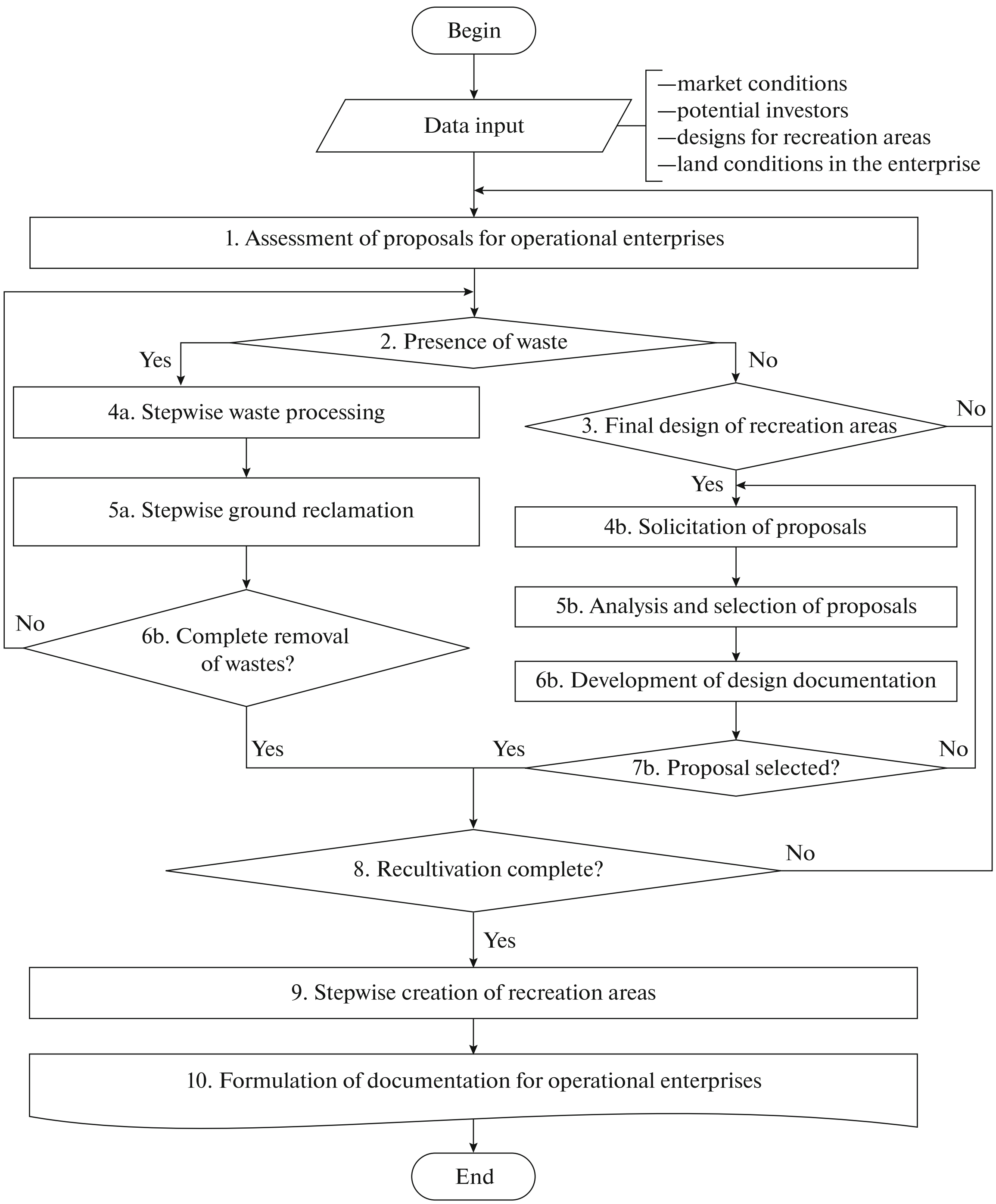
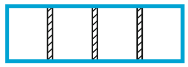
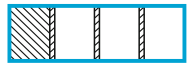
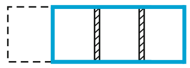
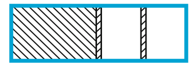
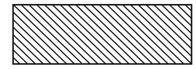
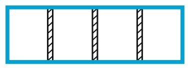
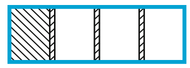
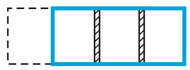
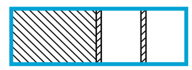
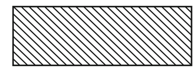
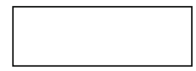


Fig. 1. Management of the stepwise processing of iron-ore waste at operational enterprises.

waste processing (step 4a) and land reclamation (step 5a). In parallel, a plan for the creation of recreation areas is developed and proposals are solicited (steps 3 and 4b), with subsequent selection of the best proposal (step 5b) and the development of design documentation (step 6b). In establishing the recreation areas (step 9), it is assumed that the waste has been completely removed (step 6a), the best proposal has been adopted (step 7b), and the newly available land has been recultivated (step 8).

In the first phase of the project (Table 1), the wastes are removed from the first section of the dump and processed, with subsequent reclamation of the newly available land. Analogous processes are conducted in all the other sections of the dump (from phase 1 to phase $n - 5$). To create recreation areas,

Table 1. Chart of measures for rational environmental management

Sequence of phases	Object	Initial state	Restoration stage 1	Restoration stage *k*	Final stage
Phase 1	Section *l*, dump 1		Waste removal  Land restoration 	Waste removal  Land restoration 	Waste removal  Restored land for recreation areas 
Phase 2	Section *l*, dump 1		Waste removal  Land restoration 	Waste removal  Land restoration 	Waste removal  Restored land for recreation areas 
...	...	...	...	...	...
Phases (n – 5) – n	Contiguous territory	Gravel and/or asphalted roads, railroad tracks	Removal of railroad tracks and any asphalt, gravel, and other material present	Restoration of ground surface	Planting of grass
Phases (n – 3) – n (contracted out)	Foundations	Restored dumps, trenches	Reinforcement of side walls for the creation of ponds; or filling of foundations	Introduction of fish in artificial ponds/fertilization of filled basements	Acclimatization of fish/planting of grass
Phase n	Buildings and structures	Mine buildings and structures	Removal and sale of equipment	Dismantling or modernization of buildings and structures for recreation areas (parks, etc.)	Buildings and structures ready for use

contiguous territory within the plant is prepared: where necessary, the transport infrastructure is dismantled, with subsequent restoration of the ground and the planting of grass (phases n – 5 to n). At the same time, proposals are sought for the development of recreation areas (phases n – 3 to n). The territory and buildings are prepared for their creation (phase n).

The waste-free and low-waste technologies are introduced in parallel (phases 1–n), as illustrated in Fig. 2. Preparations for the creation of the recreation areas continue while the enterprise is still operational. After complete removal of the wastes from the section of the dump (phase n – 5), proposals for development of the recreation areas are solicited. The inauguration of the recreation areas follows the closure of the enterprise (phase n + 2). In contrast to standard reclamation projects, where the recovery of the land takes more than five years, the proposed schedule permits opening of the recreation areas within three years of the closure of the mining enterprise.

The management of the stepwise processing of iron-ore waste at enterprises that have closed (Fig. 3) differs in that uses are sought for the wastes and sources of external finding are researched. Assessment of the options for the introduction of waste-free and low-waste technologies at the closed enterprise (step 1) is followed by verification of the availability of the necessary funds and resources (step 2). Waste processing and land reclamation are financed by selling the basic resources of the enterprise (step 3) and attracting investors (step 4), as well as state subsidies.

In the last steps, the waste is processed (steps 5 and 9) and the land is recultivated (steps 6 and 10). If the funds are insufficient, some of the iron-ore waste may

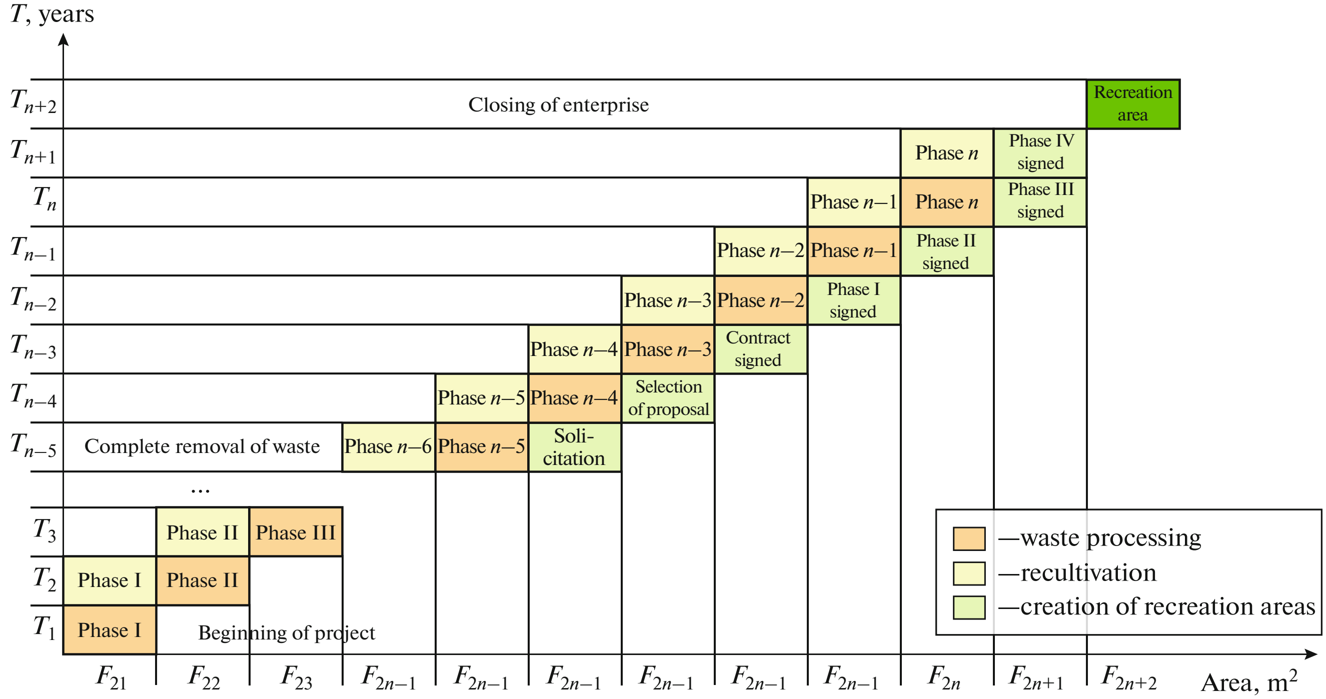


Fig. 2. Schedule for waste processing, land reclamation, and the development of recreation areas.

be used as construction materials in the reclamation program or transported to other enterprises for further utilization. In the absence of plant resources, financing must be provided by outside investors (step 8). The recreation areas are established (step 12) after waste processing and recultivation of the land (steps 7 and 11).

The management of stepwise processing of iron-ore waste for ongoing projects is shown in Fig. 4.

The options for introducing waste-free and low-waste technologies are assessed (step 1), with monitoring of the waste accumulation (step 2) and the damage to the ground cover (step 3). If problems are detected, technologies for waste processing and for recultivation are analyzed (steps 4a and 4b) and subsequently applied (steps 5a and 5b). Periodic monitoring prevents environmental damage (step 7). While the enterprise is functioning, recreation areas are successively created (step 8). They go into use after the enterprise has closed (step 9).

On the basis of these management procedures, five proposals are made for the introduction of waste-free and low-waste technologies in the Tashtagol region of Kemerovo Oblast. Basically, we propose the construction of a waste-processing system in 2017 and 2018, with the creation of recreational green space and the generation of useful products. Those products are different for each proposal, as follows.

(1) Construction materials (filler for roads, causeways, dams, etc.).

(2) Iron-ore concentrate produced by heap leaching with sulfuric acid.

(3) Iron-ore concentrate produced by biological leaching.

(4) Gold-ore concentrate produced by biological leaching.

(5) Gold-ore concentrate produced by leaching with hydrocyanic acid

The system would go into operation in 2019 and reach its design capacity in 2020. Systematic reclamation of the newly available land would begin in 2020. Establishment of the recreation areas is planned for 2031.

Such technologies are simulated by means of SciLab software [18, 19]. For purposes of selection, the proposals are ranked. We may state the ranking problem as follows.

RANKING THE PROPOSALS

We are given a set of proposals A_s, $s \in [1, S]$. Each proposal s is characterized by variables f_x ($x \in [1, 3]$): the economic impact (f_1); the area of damaged and restored land (f_2); and the population with standard socioeconomic indices (f_3). We distinguish between three levels of public health and environmental safety: low (L), $fn_x \in [0, Y_{x1}]$; moderate (M), $fy_x \in [Y_{x1}, Y_{x2}]$; and high (H), $fv_x \in [Y_{x2}, 1]$. Here Y_{x1} is the boundary between the low and moderate safety levels; and Y_{x2} is

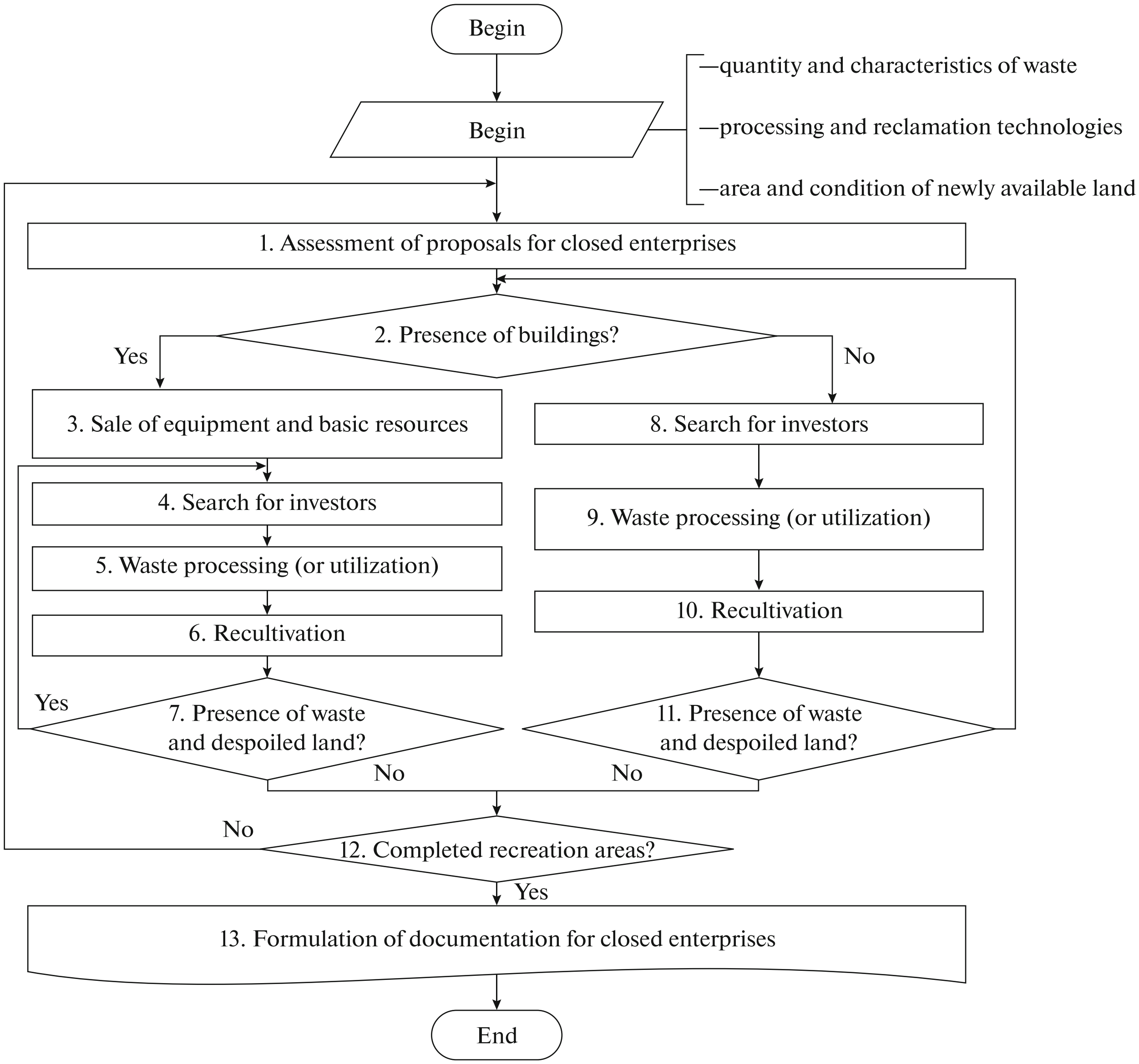


Fig. 3. Management of the stepwise processing of iron-ore waste at closed enterprises.

the boundary between the moderate and high safety levels. Each proposal *s* is characterized by proportion *w* of the high safety level, proportion *g* of the moderate safety level; and proportion *b* of the low safety level.

The goal is to rank the proposals. Proposal $A_1^{\mathrm{rank}(1)}$, which is superior to proposal $A_0^{\mathrm{rank}(z)}$ in terms of the proportion *w* of the high safety level, is assigned the first rank if

$$\sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{i=1}^{I}\left(Kp_{tmni}+Kz_{tmni}-Gi_{tmni}\right)\to\min, \quad (1)$$

where KP_{tmni} and Kz_{tmni} are the capital expenditures for the introduction of waste-free production and the development of recreation areas, respectively, in period *t* at enterprise *n* in region *m* for phase *i* of the process, rub; Gi_{tmni} denotes state, private, and other subsidies, rub.

We assume here that

$$w\left(A_1^{\mathrm{rank}(1)}\right)\geq w\left(A_s^{\mathrm{rank}(z)}\right)\ \text{when}\ z\in[1,3]. \quad (2)$$

Proposals with $w = 3$ are regarded as priorities; those with $w = 2$ as acceptable; and those with $w = 1$ as of no short-term interest (or as reference proposals).

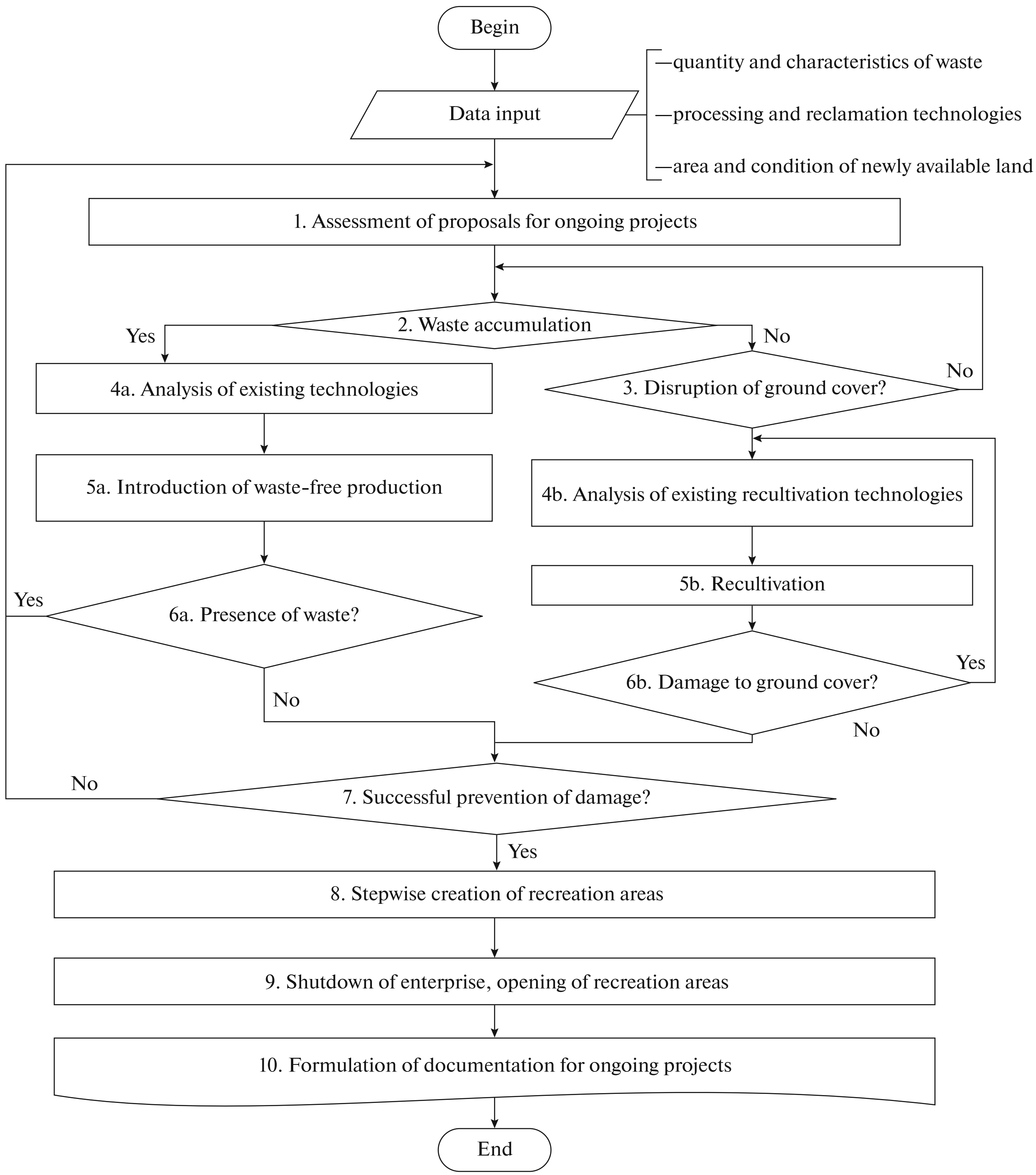


Fig. 4. Management of the stepwise processing of iron-ore waste for ongoing projects.

The values of Y_{x1} and Y_{x2} are determined on the basis of expert opinion [20]. They may change in accordance with the social, economic, and environmental conditions in the mining region. Table 2 presents the ranking of the proposals.

On the basis of the ranking, we conclude that proposals 2 and 4 are priorities, while proposals 1 and 3 are acceptable. The final choice of proposal from those of rank will depend on the preferences of the person making the decision.

Table 2. Ranking of proposals for waste-free and low-waste technologies in the Tashtagol region of Kemerovo Oblast

Proposal	f_1, 10^6 rub	f_2, 10^3 m^2	f_3	Safety level			Rank
				f_1	f_2	f_3	
1	841.02	9.65	114	H	H	M	2
2	601.50	9.50	166	H	H	H	1
3	412.11	9.50	161	M	H	H	2
4	590.50	9.30	121	H	H	H	1
5	263.00			L	H	L	–

CONCLUSIONS

The procedures for systematic processing of iron-ore waste in mining regions differ in algorithmic structure for operational enterprises, enterprises that have been shut down, and ongoing projects, in terms of the documentational, technological, and financial aspects of the enterprise's life cycle.

The procedures here outlined are based on schedules and parallel stepwise processes for waste processing and land reclamation. They ensure rational resource management, maximum economic benefit from the introduction of waste-free production, and improvement in the social and environmental conditions in industrial regions.

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