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ECONOMICAL AND NATURAL CONDITIONS APPLICABLE TO THE DEVELOPMENT OF POST-MINING AREAS

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Abstract. The cost of establishing of new land-use forms depends on the selected development type and natural conditions found in the mining area, which is usually comparable with the profits from mining products. In the active mine, it is possible to shape final pits, overburden and waste heaps, and to plan infrastructure in such a way that redevelopment of the area can be cheap and possibly multifunctional. Still better results can be achieved, if at the stage of strategic planning influence of the geological environment, relief and landscape, water conditions, vegetation and nature protection on the future development is assessed and potential users of the post-mining area are identified.

In Europe usually bio-reclamation has been preferred creating arable lands, forest grounds or water ponds. The natural conditions indispensable in obtaining success there are generally known. These conditions are presented in the main part of this paper. The pledge that the nature will be reintroduced helps in social acceptance of the environmental impact statements and further mining projects. In alternative revitalisation types, such as creation of industrial and/or housing programmes, service sector, waste disposal sites, and recreational-sport grounds, combined with land shaping, the reconstruction of productive soil is of minor importance. Moreover, new land-use forms should make possible future exploitation of mineral resources. However, these new functions are still environmentally constrained. General economic, social, cultural, juridical, and technological factors play also their roles there.

Resulting from multitude of factors and criteria, two types of approaches are observed. There are attempts to rank the factors and determine the criteria for optimal type of redevelopment and establishment of standard procedures. On the other hand, an individual set of conditions for a mine site stimulates the designers creativity and leads to such projects which are functional and well composed within the local environment.

Key words: post-mining areas, reclamation, redevelopment factors and criteria.

Abstrakt. Koszt wykorzystania terenów pogórniczych zależy od miejscowych warunków przyrodniczych oraz od wybranego kierunku przyszłego rozwoju tych terenów. Koszty te są zwykle porównywalne z zyskami ze sprzedaży produktów górniczych. Jednakże już w czynnych kopalniach można kształtować końcową odkrywkę oraz hałdy nadkładu i odpadów górniczych, a także zaprojektować infrastrukturę kopalnianą w taki sposób, aby dalszy rozwój obszaru pogórniczego był tani i możliwie wielofunkcyjny. Jeszcze lepsze wyniki można osiągnąć, jeśli na etapie strategicznego planowania zostanie przewidziany wpływ środowiska geologicznego, rzeźby terenu, krajobrazu, warunków wodnych, roślinności i ochrony przyrody na przyszły rozwój obszaru pogórniczego i jeśli zostaną określeni potencjalni jego użytkownicy.

W Europie preferowana jest zwykle rekultywacja biologiczna obszarów pogórniczych, ukierunkowana na tworzenie gruntów ornych, terenów leśnych oraz zbiorników wodnych. Warunki przyrodnicze niezbędne do osiągnięcia tych celów są w ogólności rozpoznane. Przedstawione zostały one obszernie w niniejszym artykule. Z kolei wczesna informacja o tym, że kierunki przyrodnicze zostaną odbudowane po zakończeniu eksploatacji, bardzo pomaga w uzyskaniu społecznej akceptacji dla raportów wpływu górnictwa na środowisko oraz dla planów dalszego rozwoju górnictwa.

Odtwarzanie ziem uprawnych jest nieistotne w przypadku alternatywnych, niebiologicznych typów rewitalizacji terenów pogórniczych, takich jak: budownictwo mieszkaniowe, rozwój przemysłu, usług, budowa terenów rekreacyjno-sportowych połączona z kształtowaniem nowej rzeźby terenu terenu, a nawet tworzenie składowisk odpadów. Ponadto nowe formy wykorzystania terenu powinny umożliwić przyszłą eksploatację kopalin. Każdy z tych kierunków posiada jednak swoje ograniczenia

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środowiskowe. Czynniki ekonomiczne, społeczne, kulturowe, prawne i technologiczne odgrywają tu także ważną rolę. Znane są dwa sposoby rozwiązania problemów wyboru, zależne od wielu czynników i stosowanych kryteriów. Dlatego też podejmowane są próby stworzenia standardowych procedur decyzyjnych, a także rankingowego uszeregowania tych czynników i określenia kryteriów optymalnego wyboru typu zagospodarowania obszarów pogórniczych. Z drugiej strony specyficzny zespół warunków każdego obszaru górniczego z osobna inspiruje projektantów do tworzenia projektów funkcjonalnych i dobrze wkomponowanych w lokalne środowisko.

Słowa kluczowe: obszary pogórnicze, rekultywacja, czynniki i kryteria rozwoju obszarów pogórniczych.

INTRODUCTION

Definitive closing of mines is a normal result of mining activity and the non-renewable nature of mineral reserves. However, early economical theories did not take into account environmental consequences or external costs of the process. Since the onset of the mankind history, mining has left derelict sites but only recently we are witnessing this fact on a mass scale, aggravated by economical and social transformations of the mining sector of Poland. Some transformation features are presented in Table 1.

Responsibility and control of derelict sites in Poland have been handed over into the hands of District Governors. According to the new regulations, a District Governor accepts general plan and final results of reclamation, which are often imprecisely stated. It is sufficient to choose one of four possible end-uses: water, agriculture, forest or other purposes. However, much incompetence exists: local authorities are not sufficiently prepared to assess land suitability for future use and to control if the executed reclamation has been proper and sufficient.

The following case illustrates the problem. In recent years, the public opinion in Poland has been alarmed of illegal, local exploitation of aggregates (Burnat, 2000). The developers declared construction of fish ponds, which is generally supervised by local construction authority and does not need mining concession. In fact and instead, they mined and depleted mineral resources, achieved high profits from selling aggregate without paying taxes and, finally, left abandoned, water-filled hollows not suitable for fish farming at all.

Relation of public policy to reclamation goals and responsibilities was presented by Doll as early as in 1988 and then by Malewski (1999), Warhurst, Noronha (2000), and others, but it is clear that implementation of the rules depends much on the legal and management systems existing within a country. Only recently in Poland, the Government Programme for Post-industrial Lands has been accepted by the Council of Ministers (MŚ, 2004). It meets the obligations declared in the 2^{nd} Environmental Policy of the State (MŚ, 2000) and related programmes developed in 2002–2003.

Vast post-mining areas appear to be a real challenge to sustainable development in our country and in many countries of the world which have or had mining industry. Extensive pollution observed in the districts with extractive industry frequently appears not to have a present-day origin but to be inherited from previous activities. Therefore, the "polluter pays" principle cannot be applied in such cases. In some areas, land-use was completely changed and unsuspected derelict sites are discovered among settlements or within agriculture lands (Lis, Pasieczna, 1997, 1999; Lis *et al.*, 1999; Warhurst, Noronha, 2000; Pasieczna, 2003; Verraes, 2005).

Table 2 shows an illustration of the magnitude of the space involved. To receive the real financial impact, these data should be multiplied by the unit costs of a given reclamation type (Table 3). It can be noticed that costs of securing new use of mined-off area are very high, in some cases of the same order of magnitude as the costs of developing the original mining

Table 1

Transformation of the mining industry in Poland

FORMER	PRESENT
• State-owned mines • Mass development of extensive mines • Outset of reclamation practices — mostly agriculture and afforestation • Hidden cost of reclamation, external — state financed	• Private and state-owned mines • Mass scale closure of mines, few small mines opened • Extensive areas to be reclaimed — innovative land-uses • Costs increasingly known, internalised, new government programme (2004) for derelict sites
• Stable law • Centrally controlled autarchy policy	• Permanently adapted law • Environment- and democracy-oriented policy, some incompetence

Table 2

Dimensions of some lignite open pits/dumps in Poland and their reclamation

Mine	Final surface (ha)	Depth (m)	Reclamation made or foreseen
Bogdałów	8.5	10	agriculture, forests, water
Władysławów	157	36	water
Adamów	430	47	water
Koźmin	231	39	water
Lubstów	12	~ 90	waste dump (municipal)
Gosławice	320	27	waste dump
Pątnów	332	~ 60	waste dump
Pątnów	360	60	water
Pątnów	57.7	~ 60	industrial
Kazimierz	110	60	mixed (recreation complex)
Turów	2,230* + 1,850 d	up to 300	forest
Bełchatów	2,400* + 1,520 d	200–280	forest, waste dump, water
Szczerców	<2,000*	200–280	?
Lubstów	408 d	40**	agriculture and forest
Morzysław/Gl.	25 d	8–20**	1–2 — storey buildings
Pątnów-Jóźwin	340 d	70**	forests

* mined surface d — dump
** height (m)

Table 3

Typical costs of post-mining reclamation in Poland (PLN)*

Type	Unit cost (PLN/ha)	Mine	Total cost (millions PLN)
Agriculture	25,000–200,000	Machów (sulphur)	450–500
Afforestation	30,000–200,000	Szczerców (lignite)	1,500 ?
Water	0–1,000,000	Kłęczany (sandstone)	15.5
Technical reclamation = 70–80% of total costs		Osielec (sandstone)	4.9

* 1 USD = 3.6– 4.0 PLN

project. The time necessary to complete the reclamation is also comparable to the time of the development (Fig. 1). However, when the reclamation design is incorporated into a mining project, and mining equipment is used for shaping final pits and heaps, then reclamation time and related costs (property tax, fees for the use of the environment) could be significantly reduced. This is successfully practised e.g. in the Szczakowa sand mine (Bednarczyk, 2001).

Another example: in the Upper Silesia, of the total number of 69 collieries in 1989, 23 were shut down and 8 partially closed during the last decade. This shutdown has left at municipal disposal a total area of some 640 km^2 which could have great value in an industrialised district if turned into greenfields. Unfortunately, great part of this post-mining land appears to be derelict. Locally, several thousand hectares have subsided 20 metres or even more below the initial surface, causing building failures and development of wetlands.

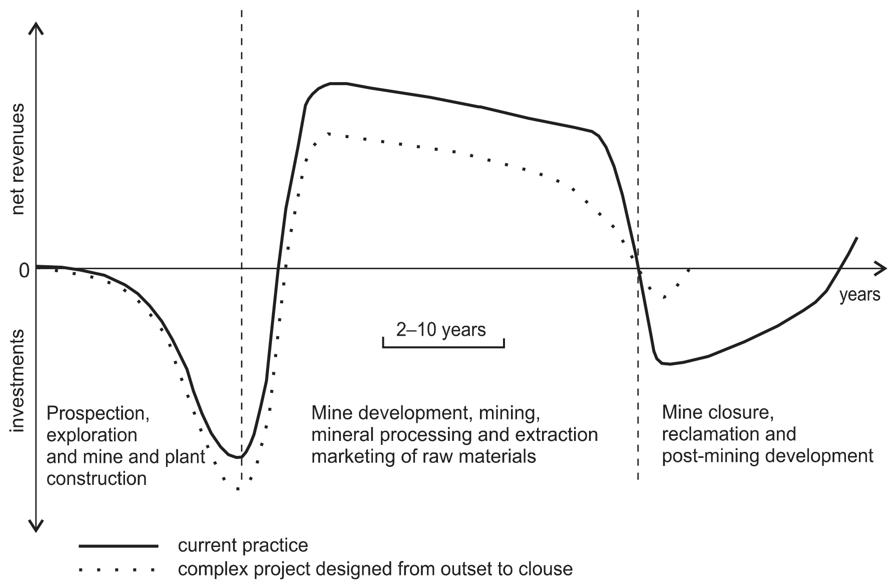

Fig. 1. Scheme of cash flow in life cycle of a mining project (Paulo, 2001, supplemented)

Note relatively high costs and extensive period of current reclamation and post-mining development

Driving force for turning brownfields into vital community assets in market economy countries, it is a commercial decision which is often part of property transaction (Kibert *et al.*, 1999). Commercial factors are, therefore, an integral part of the remediation process, and often dictate which remedial works are required and how they are to be undertaken. Such commercial factors include: cost of remediation technology, costs of on-site maintenance and management, liability, marketability and property value, and development constraints (Swane *et al.*, 1997). Redevelopment of large mineral districts forms part of the urban renewal process financed by business or government for profit, or environmental benefits, or both.

Lisowski (1997) performed clear cost-benefit analyses (C-BA) on hard coal exploitation under the Silesian cities. Figure 2 shows the C-BA ideogramme on the left, and the balance of the hypothetical build-up area costs on the right. Two options were analysed: 1) cheap mining, eliminating roof support by flush refill, though resulting in subsidence (measured by horizontal distortion) and construction damage (measured by loss/costs); 2) mining with optimised intensity, coordination, flush refill, and surface preventive measures resulting in reduced distortion. It appears that optimisation of the costs is realistic provided that monitoring and computer analyses of both mining and urban activities are carried out (*op. cit.*).

Reclamation and rehabilitation are quite recent practices, introduced on broader scale in the second half of 20th century, only. Redevelopment experience gathered until now is full of pitfalls due to excessive costs or unmet targets. There is a general belief that the earlier closure planning and pollution prevention is built into a project, the more effective and environmentally benign closure will be. The greater time lapse between the occurrence of environmental damage and its remediation, the greater (in most cases) human and financial resources are required to address the problem. Planning of the closure from the outset will enable a company to provide for the closure costs during the period of positive cash flow. It requires that investments to environmental quality be put in place, or ensures that at the time of closure the site is rehabilitated and in the condition that is commensurate with the expectations of the community (Warhurst, Noronha, 2000).

Planning starts from choosing a viable alternative use. Theoretically, there are many alternatives (Table 4), but in practice they are controlled by natural, economic and social conditions and constraints. Evaluation of land-use alternatives is a sequential process (Sweigard, Ramani, 1986) including socio-economic and environmental analyses, and a comparison of benefits (Table 5) at preliminary stages as well as economic, environmental, and social impact assessments at final stages (Fig. 3).

Table 4

Land-use alternatives

Close to nature		Municipal and industrial construction grounds	
Productive soils	Surface waters		
Agriculture – crop cultivation, pastures	Fish ponds, aquaculture	Residential	Industrial
Forestry	Wetlands	Institutional	Waste dumps
Recreational		Commercial	Infrastructure
Wildlife habitats			

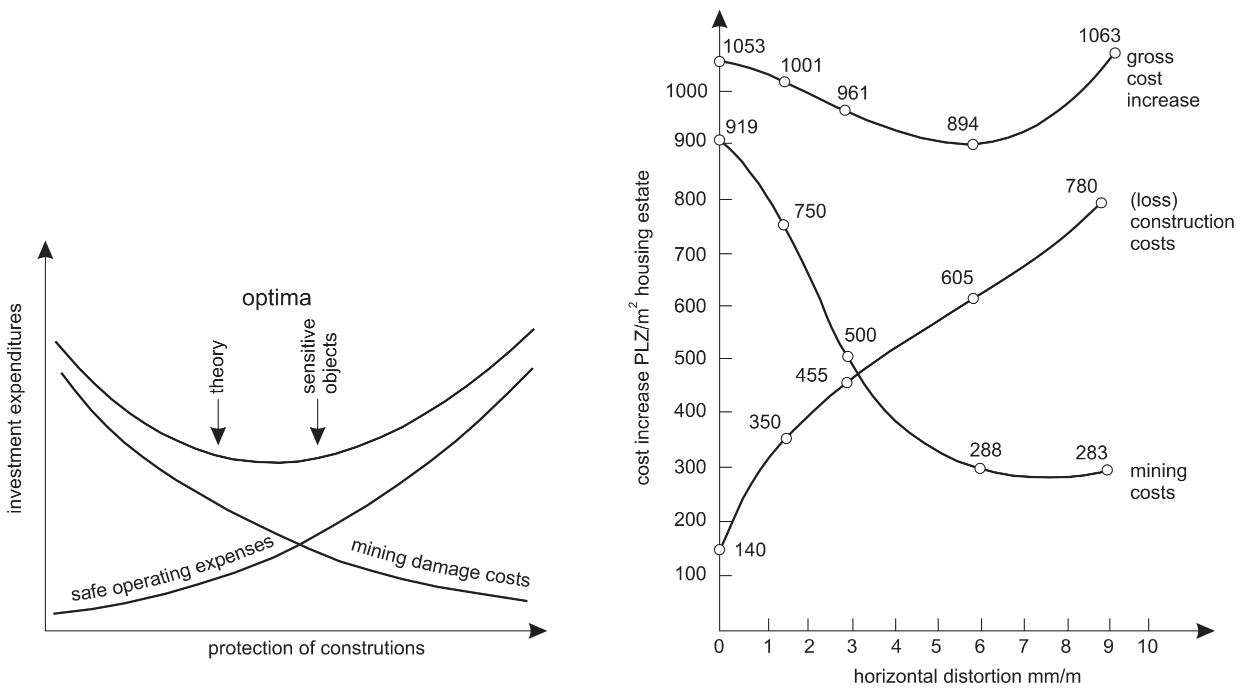

Fig. 2. Optimization of mining decisive process by cost-benefit analysis (Lisowski, 1997) Katowice case study: underground coal mining methods under the town

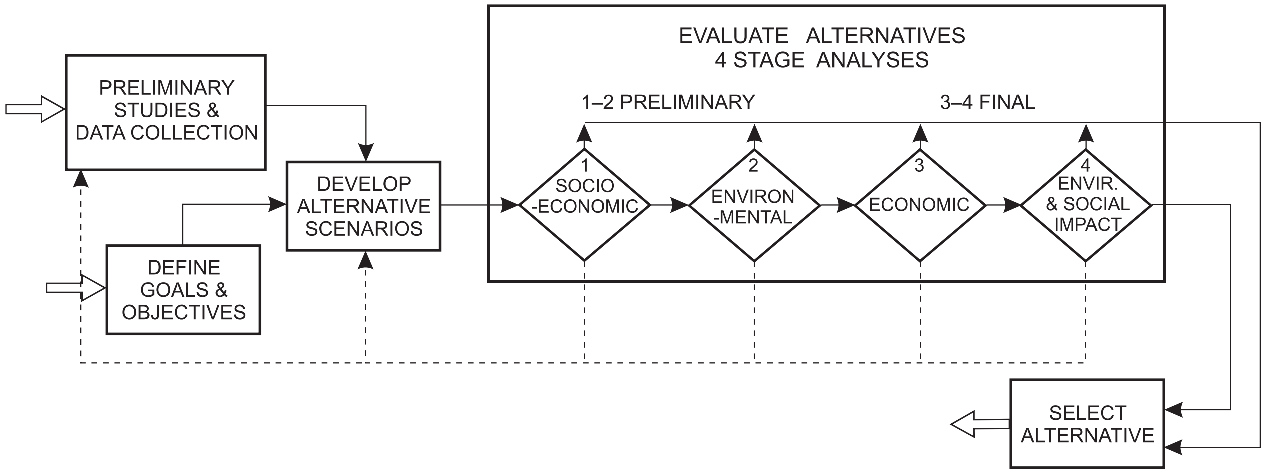

Fig. 3. Process of the evaluation of land-use alternatives (Sweigard, Ramani, 1986)

Each stage is followed by a decision that allows to move to the next step or return to the initial one. As usually, a preliminary consideration of economic and social factors eliminates a number of potential land end-uses. The current data are obtained from local authorities and compared with local building, infrastructure development, and environmental management plans. Applying relevant check lists, distinct environmental factors are revised to find if there are any physical constraints to the end-use of plots. For instance, pyritic rocks exposed on the surface where they easily weather and lower pH, will hamper a recreation use of the nearby water reservoirs. Later on, when new data are obtained, redefinition of goals

Table 5

Relative benefits of end-use options in temperate climates (Coppin, Box, 2000)

Use		Economic	Landscape	Amenity/Wildlife
Agriculture	arable land	moderate to high, depending on local agricultural conditions. Takes time to establish	high where field boundaries are retained; restored land can provide a variety of colour and texture. Moderate where praire farming practiced	very low unless low input/organic farming techniques are used
	pasture	moderate to high for dairy and beef production	high where traditional farm boundaries are retained	low unless low input/organic farming techniques are used
	rough grazing	low	moderate to high, depending on vegetation	moderate, but grazing intensity may cause damage to vegetation
Forestry	timber or pulp	moderate but requires long-term investment	moderate when properly planned	low when pure monoculture; moderate-high in mixed planting
Energy crops	biomass, woody or non-woody	moderate	moderate when properly planned	low to moderate, depending on the crop
Conservation	biodiversity/wildlife habitats	low, unless as a part of wider attractions	high, especially with a variety of habitats or extensive areas	high
	industrial heritage		high, if areas maintained as part of local landscape	moderate to high
Recreation and tourism	intensive uses (golf, fishing)	high, can be maximised through tourism	low to moderate depending on the activities	low to moderate, depending on the activities

and development of alternative scenarios may take place. The final economic analysis conducted in stage 3 (Fig. 3) may appear in various forms. The simplest one would estimate the resale value of the land after completion of the reclamation, based on real estate transactions in the region. A more complex alternative would compare the income from land reclaimed, e.g. from crops, and the costs in the overall cash flow of the project.

Final analysis of environmental and social impacts (Fig. 3) is performed only in the case of two or more alternative end-uses of economic importance. Then comparison of environmental impact of the alternative plans is assessed by means of Leopold *et al*. (1971) matrix, whereas social impacts could be evaluated by several methods, like checking list, simulation, C-BA, input-output tables, and tendency extrapolation. In the recent years, multi-criteria decision techniques and land-use capability classification are used.

For the construction purposes, the stability of ground and depth of groundwater table appear to be the leading factors. All factors (Tables 6 and 7) can be linked with various potential land-uses applying a land suitability classification. An early version of this classification was prepared for forest and agriculture reclamation in Great Britain by Coppin, Bradshaw (1982). Classes given by them should be modified by local climate and soils. Such land suitability classification (Tables 7 and 8) can be used:

- to suggest suitable end-uses for an existing site,
- to examine possibilities for amelioration to achieve given end-use,
- to define parameters of site design and management that are required by a given end-use,
- to compare economic and environmental costs and benefits of alternative end-uses.

Construction grounds are more sensitive to socio-economic than to natural factors, each type of utility having a specific impact factor. The data given in Table 6 should be considered as specific examples, not as generalised handbook values. General requirements for typical land-uses and possible technical solutions are given in Table 9. Reclamation requirements will be discussed in detail later on.

Three categories of end-uses are distinguished in the Ontario Guidelines' (MNDM, 1992):

- A *walk away* status, without residual constrains of the future use of the land remaining after rehabilitation is completed, with no additional monitoring or maintenance requirements.
- *Passive care*, with minimal need for monitoring and infrequent maintenance of non-critical structures.
- *Active care*, requiring regular operations, monitoring and maintenance of atypically managed site; permanent constraints of the beneficial use of the land exist, e.g. heavy metal concentration (Lis, Pasieczna, 1999).

Only the *walk away* or *passive care* status means proper rehabilitation, i.e. resources required for maintenance of land are consistent with industrial, crops, amenity or wildlife benefits. Planning of disposal sites has to consider the long-term ability of the land to be reclaimed to a beneficial end-use. *Active care* needs provision for considerable resources for a new purpose site adaptation. The land could rather be a long-term future asset than a liability to be discharged as quickly and simply as possible.

For each situation and site, the feasibility of the available rehabilitation or restoration options has to be examined taking into account ownership as well as engineering and ecosystem factors. Creation of complex wildlife habitats has implications for long-term ownership, and the provision and funding of wildlife management.

Table 6

Relative importance of natural and anthropogenic factors as determinants of land-use (Sweigard, Ramani, 1986, modified)

Natural factors	End-uses							
	Biotic env.			Built environment				
	F	A	R	B	O	C	I	W
Topography (relief)	1	2	0	1	1	1	1	1
Slope	2	2	1	1	2	2	2	1
Altitude	1	1	0	0	0	0	0	1
Exposure	1	1	0	0	0	0	0	0
Drainage/impermeability	2	2	0	2	2	2	2	2
Temperature	2	2	1	0	0	0	0	0
Precipitation	2	2	1	0	0	0	0	1
Consolidated overburden	1	2	1	1	0	0	0	1
Soil properties – agricultural	1	2	1	0	0	0	0	0
engineering	0	1	0	2	2	1	1	2
Total – natural sensitivity	13	17	5	7	7	6	6	9
Socio-economic factors	End-uses							
	F	A	R	B	O	C	I	W
Location	0	1	2	2	2	2	2	2
Accessibility	0	1	1	2	2	2	2	1
Size and shape of site	0	2	0	1	0	2	2	1
Surrounding land uses	0	1	1	2	2	2	1	2
Population characteristics	0	1	1	2	1	2	1	2
Land ownership	0	0	1	1	1	1	1	1
Regulatory constraints	0	1	1	2	2	2	2	2
Company attitudes	1	1	1	2	2	2	2	2
Total – socio-economic sensitivity	1	8	8	14	12	15	13	13

F – forests, A – arable, R – recreational, B – residential buildings, O – offices, C – commercial, I – industrial, W – waste dump
Impact: 0 – small, 1 – moderate, 2 – high

Table 7

Agriculture and forestry land suitability classification

Site factor		Limitations	Land suitability class (decreasing)				
			1	2	3	4	5
Gradient		<11°	×				
		11–18°		×			
		18–25°			×		
		>25°					×
Exposure		sheltered	×				
		moderate		×			
		distinct			×		
		severe				×	
Soil	type of subsoil material	silt	×				
		sand			×		
		mica		×			
		till		×			
	depth (m)	>0.3	×				
		0.05–0.3		×			
		<0.05				×	
	stone content (%)	<10	×				
		10–35		×			
		35–50			×		
		>50				×	
	water available to plants (mm/year)	250	×				
		200		×			
		120			×		
		80				×	
		50					×

Following conditions in post-mining areas should be assessed in the long term:

- physical stability of structures and workings that remain after mine closure and rehabilitation,
- chemical stability of rock material, mobilisation and dispersion of pollutants into the environment,
- land-use compatibility of the reclaimed site with the surrounding land (Fig. 4).

Returning the land to beneficial use, either in its original state or for some new purposes, involves rehabilitation and re-vegetation. Both rehabilitation and re-vegetation are rather

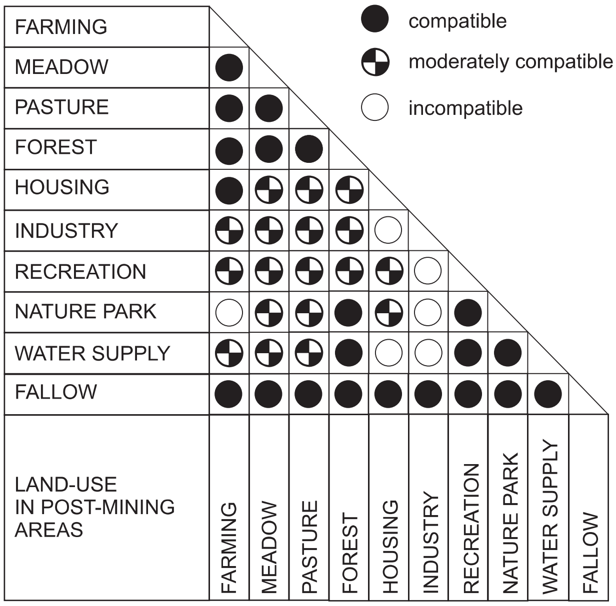

Fig. 4. Matrix of land-use compatibility (Geominero, 1996)

Table 8

Potential end-uses and land suitability classification of fire clay wastes in a lignite mine

End-use		Land suitability class (decreasing)				
		1	2	3	4	5
Agriculture	arable	•				
	pasture	•	•			
	rough grazing		•	•	∘	
Forestry	timber	•	•	•		
	firewood	•	•	•	∘	∘
Nature conservation	woodland	•	•	•	∘	∘
	semi-natural scrub	•	•	•	•	•
	moor and wetland			•	•	∘
Recreation	intensive	•	•	•	•	•
	extensive			•	•	•

• sustainable uses based on present knowledge
∘ potential uses given further research and development

Table 9

Post-mining land-uses — requirements and possible solutions for implementation (Geominero, 1996, supplemented)

Land-use	Requirement	Solution
Agriculture	• large and shallow open pits • chemical limitations: pH, salinity, toxic components • physical limitations: stone content ≤15%, slope angle ≤5° arable land, ≤15° pasture, water availability, limited erosion	• remodelling of slopes • supply of humus, cal or milled limestone, mud, fertilizers, im-mobilisation of toxic substances • regulation of water regime • introduction of plants
Forests	• soils not necessarily fertile, low cohesive layer above water table >0.5–1m thick (depending on introduced tree species) • slope angle = ≤35° (70%) • surface > 0.25 ha	• supply of humus and mud, and sometimes fertilizers, • drainage amelioration • introduction of plants
Nature protection	• minimal requirements, frequently grounds suitable to lay a lawn, turf and plant trees	• introduction of grass, leguminous plants and some trees
Recreation and sport	• slope stability • lack of elements generating accidents • recreation and education need usually extensive surfaces >10 ha • location near settlements	• shaping the surface • adequate constructions barriers and protective nets • introduction of grass and other plants
Settlements and industry	• slope stability and safe of erosion • studies of geotechnical properties of soil • location near settlements	• shaping the surface • drainage • improvement of soil properties • protective constructions
Waste disposals	• studies of ground permeability • studies of waste properties • location: hidden sites, not bothersome, rather close to settlements and other waste sources	• sealing the rock substratum and/or using (geo)membranes • improvement of surface and internal drainage

processes than specific events involving just the return of stored soils and the introduction of vegetation. Therefore, careful definition of the output (the final land-use) will determine the type and duration of the inputs (materials or cultivation) required to drive the overall process. Monitoring of the process may determine the need for further inputs. The resultant feedback will ensure that the necessary resources are deployed to maintain progress towards the desired end-use.

The extent of environmental hazards and the costs of mitigating them are site-specific and will be controlled by local geology, geography, and climate. The ability of a site to achieve a given end-use depends on the viability of the developed rock-soil-plant-animal system (ecosystem) or the rock-water (-plant-animal) systems (water storage and/or ecosystem). The development into ecosystem-dominated land uses is controlled by a number of factors including:

- drainage and groundwater conditions,
- slope and erosion,
- climate, exposure, and resulting soil-water availability,
- soils and soil-forming materials,
- cultivation requirements or vegetation management,
- effect of animals on the developing vegetation.

The last two factors concerning ecology are only marginally presented in this paper which aim is to evaluate influence of inanimate nature factors. Built environment-dominated systems, some derelict sites, and underground mined or post-mining areas of low natural value may be developed for construction use. The ability of a site to achieve such an end-use depends essentially on the ground stability and pollution. Living environment plays in this case a subordinate role.

DRAINAGE AND GROUNDWATER CONDITIONS

Two situations: bowl-shaped depression in impermeable massif as well as shallow depth of groundwater level, and concomitant high permeability are decisive in choosing one of water reclamation types (Fig. 5). Drainage pumping in the future is the costly alternative. Such closed depressions are formed in place of large open pits within rather flat terrain and when surface subsides over collapsing underground workings. This second process develops even many years after exploitation ceases, and frequently overlaps the rise of the water table in effect of vanishing depression cone when mine drainage is switched off. It should be foreseen in the reclamation plan.

post-mining urban areas of the reshaped brick-clay pits, former alluvial mining, and settling ponds (Goh, Osman, 2003).

Surrounding grounds affect water quality, and in the case of salt massifs, sulphur- or pyrite-bearing rocks, and other toxic grounds, hydroisolation is necessary what greatly increases costs of reclamation.

Slope inclination is an important factor in the case of recreational swimming pools; the beach should be inclined 3–5° only, especially when frequented by children (Fig. 6). Artificially formed lakes should have shallow shelves suitable to reach the shore, tie boats, built piers, jetties or small marinas, etc. Shoreline shall have coves, peninsulas, and an islet or two with the beach covered locally by reed, forest or clump of trees, resembling natural lake habitats. Measures to protect abrasion of steep shores, like ditch, grass or thicket belts, should be undertaken (Fig. 6).

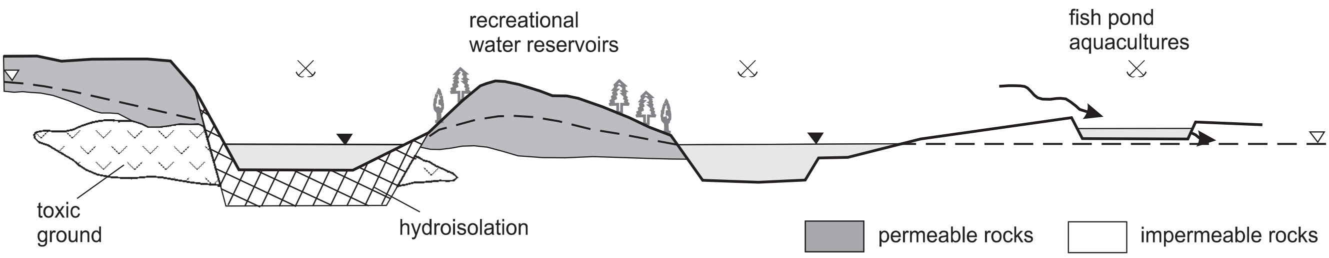

Fig. 5. Typical water reclamation situations

A spectrum of water reservoir functions includes: water storage (potable, industrial, irrigation, energy), recreational and water sports, wetlands, fish farming, water plants harvesting, landscape decorative ponds. Multifunctional reservoirs are preferred. Each specific function has its own constraints, and simple abandoning of mine workings and waiting for filling with water does not mean turning a final pit into optimal geometry. The depth and geometry of the pit as well as non-toxicity of grounds surrounding future water reservoir are essential for the most of the functions.

Usually, deep quarries or open pits exploited by the push-back method are reclaimed into isolated ponds without surface outflow. A significant depth of the resulting reservoir and poor water mixing prevents oxygenation of deeper water levels where anaerobic bacteria develop. Therefore, desirable is construction of the final pits shallower then 10 metres. This allows also for water rescue actions of bathing visitors to be effective.

Wetlands defined as the areas saturated with water or covered by shallow water, turned into the nature reserves or development sites, are playing essential cultural and socio-economic functions. Hydrologic conditions are the most important variable in wetland design. They include: seasonal pulses of precipitation, evaporation, inflow-outflow rates, retention time, freezing, water depth and the highest and lowest shoreline. Slopes must be shaped to guarantee safe access by people, pet and wildlife. Visual quality is essential for social function. Landscape decorative ponds are preferentially formed in

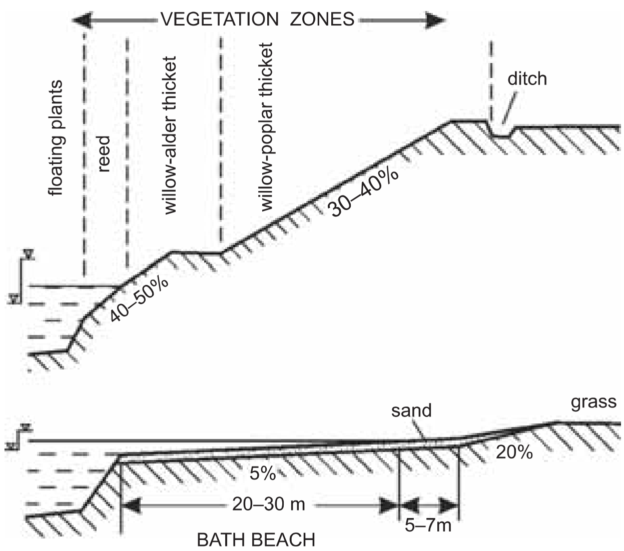

Fig. 6. Final slope profiles of pits turned into recreational reservoirs and vegetation introduced

Table 10

Hydrogeological classification of post-mining terrain for landfill sites (Geominero, 1996)

Factor	Class		
	Impermeable	Semi-permeable	Permeable
Permeability coefficient	k ≤10^{-9} m/s (k ≤0.01 mm/d)	10^{-9} < k <10^{-6}	k ≥10^{-6} (k ≥10 mm/d)
Rocks	clays, claystones, marls	siltstones, sandstones	alluvial gravels and sands, fractured limestones
Suitability	suitable, need drainage and stormwater protection	use possible if percolation zone may be rinsed out	high risk of aquifer contamination
Waste accepted for landfilling	bulk and some specialty	bio-degradable and communal waste	only harmless waste

Table 11

Important factors influencing agriculture uses

PHYSICAL	
Factor	Range and use
Stone content (at the surface)	<0.01% – cultivation without restriction 0.01–15% – hindrance in different scale >15% – not suitable
Slope inclination	<5° – cultivation without restriction, mechanised <10–12° – cultivation with special equipment <15° – seeded grassland and pastures <29° – forestry in Mid-European (wet) climate <35° – forestry in moderately dry climate <40° – angle of repose in loose rocks (dry)
Water availability	climate-dependent difficult in: hilly landscape, highlands dissected by gorges, multi-storey dumps
CHEMICAL	
Acidity/alkalinity	grounds pH <4.5 (4.0) and >8–9 are not suitable for any agricultural use including pastures, feed production and plant cultivation
Nutrients	lack of nutrients in post-mine areas restricts their agriculture use; high doses of fertilizers and agricultural treatments may improve their quality at high cost
Toxic elements	dumped overburden and poor ore as well as natural geochemical aureoles around ore deposits frequently contain toxic metals mobilised in acid environment and need neutralizers for their immobilisation; pollutants in the bedrock migrate into soils and cause diseases of animals and men

Water reservoirs, if vegetated, are usually habitats for fish and wildfowl. However, fish farming ponds need special conditions. Water depth in the ponds is usually 1–2 meters only, and for a great part of the year, it must be easily evacuated and the bottom left to plough when sufficiently dried. Therefore, pits left after mining of aggregates at low river terraces, filled with water supplied in abundance from highly permeable alluvia, are not suitable for fish farming ponds.

Groundwater conditions are very important in choosing landfill sites. A classification of post-mining terrain for this use is given in Tables 10 and 11. Internal and external drainage of the dump is always designed, and vegetation introduced to diminish percolation of atmospheric water. If the country rock permeability coefficient is not satisfactory, the construction is modified, impermeable materials used, drainage improved but this also results in the increase of overall costs.

The number of possible end-uses and necessary adaptations of a pit explains great differences of costs of given water reclamation (Table 3). In the case of the huge Bełchatów lignite mine in Poland (Table 2), a combined reclamation was chosen: filling the pit with overburden and fly ash waste from a nearby power plant, hydroisolating, and next — filling with water to create a recreational lake (KWB Bełchatów, 2002).

Protection of mineral resources may interfere with protection of groundwater reservoirs, and a general plan of nature protection. If the minerals are common in character, their exploitation below water table would not be reasonable. In Upper Silesia, to avoid exposition of large water reservoirs to aerial contamination, and to allow restoration of forests, only an upper part of thick sand deposit is mined, and sand layer 0.5–1.0 m above groundwater table is left not mined (Fig. 7). A plan of future arrangement of rehabilitated terrain may also influence incomplete exploitation of mineral resources. Figure 8 shows a case of an aggregate pit where four portions of the deposit were left as the protective pillars to form future islet and elevated land strips on which technical and recreational objects can be situated. The same portions play an important landscape shaping role (Koźma, 2000).

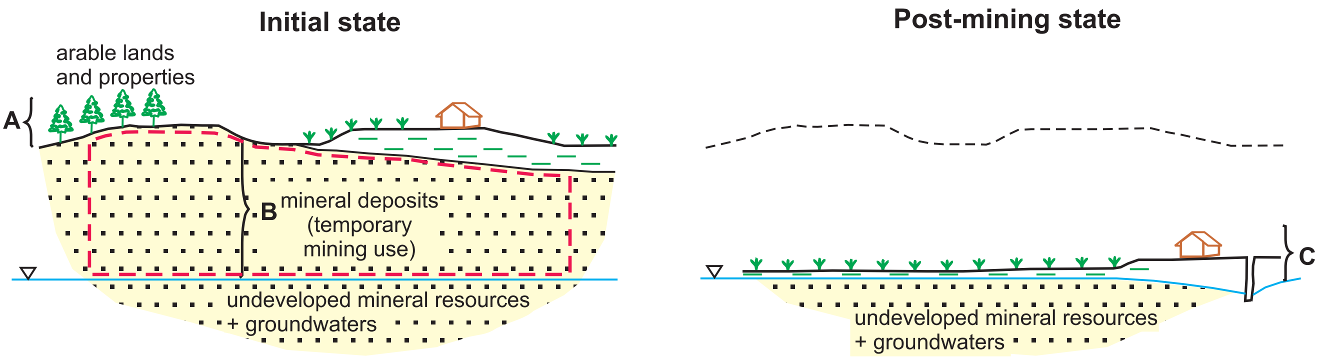

Fig. 7. Initial (A) and post-mining (C) land-use profits; profits from exploitation of a mineral deposit (B) are relatively short living and depletion of non renewable resource occurs

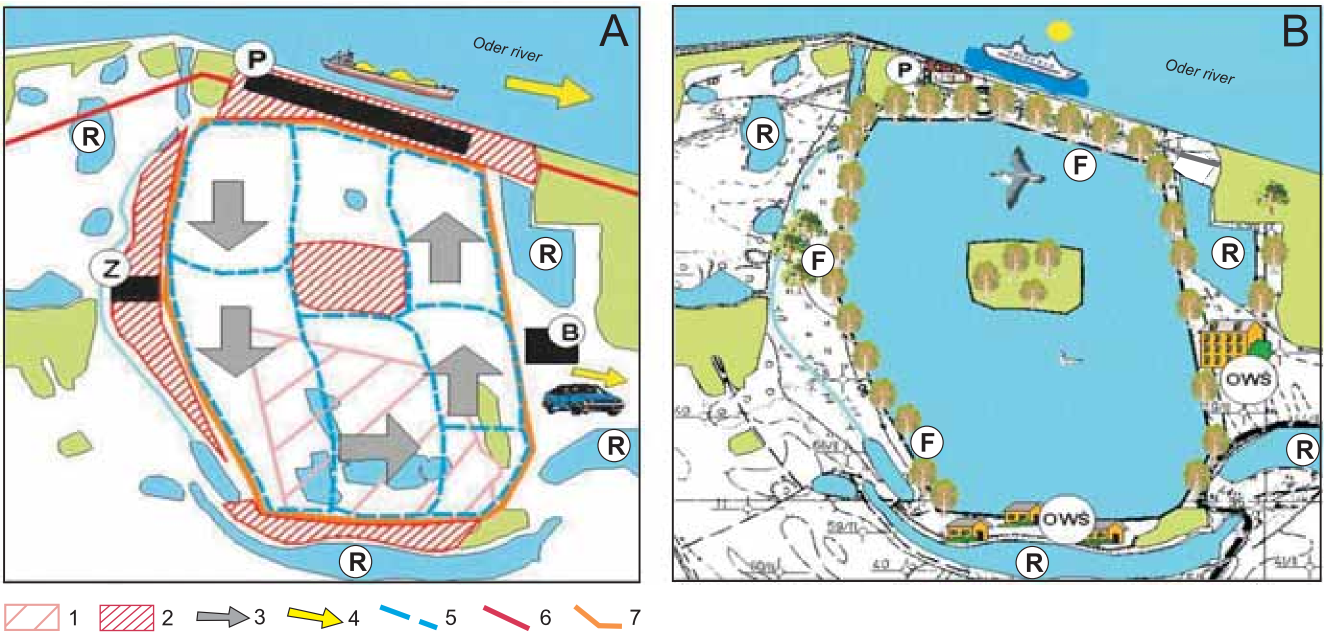

Fig. 8. Project of exploitation (A) and land end-use (B) of an aggregate deposit area, Lenartowice case study (Koźma, 2000)

1 – previous mining area, *2* – protective pillars, *3* – exploitation course, *4* – exportation of aggregate, *5* – exploitation basin limit, *6* – contour of recognized resources, *7* – contour of designed mining field; B – bureau and store-house, F – planted trees and shrubs, P – river harbour facilities, R – abandoned river arm, Z – beneficiation plant, OWŚ – recreation centre

SLOPE AND EROSION

Final pit and quarry slopes left after exploitation ceases are usually quite steep. Also steep, close to the angle of repose, are edges of mining waste disposal sites. High angle slopes determine very limited land use (Fig. 9, Tables 7 and 11). They are susceptible to erosion and mass movements (landslides). Erosion measured as an average annual soil loss is proportional to a hydrological factor (combined intensity of rainfall and runoff), slope length, slope steepness, and protective factors related to vegetation cover (Wischmeier, Smith 1978).

Remodelling of the slopes and making them less inclined is usually practised as the first step of technical reclamation. However, this is costly and not always possible. Low angle disposal sites need excessive mine surface. Lowering the inclination of former pit for the agriculture end-use can be achieved either at the cost of quarrying rocks at the rim of the pit, enlarging the mine area, or filling the pit with imported rocks or waste (Fig. 10). Both options, i.e. extensive pit infilling together with mine area enlargement are likely to occur. There are some limi-

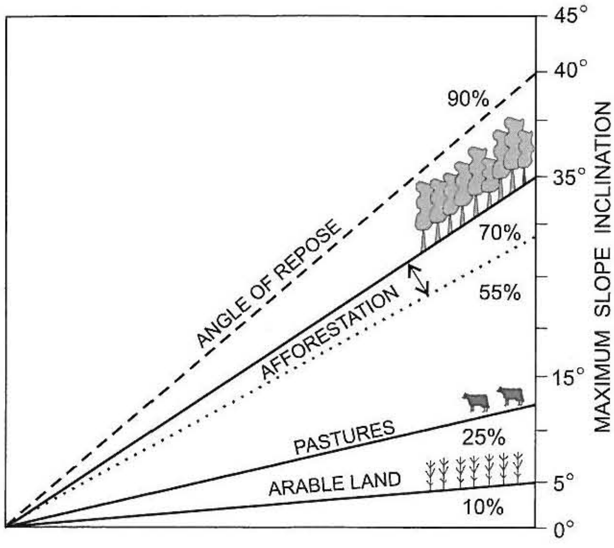

Fig. 9. Maximum slope inclinations in end-use options (Coppin, Bradshaw, 1982, supplemented)

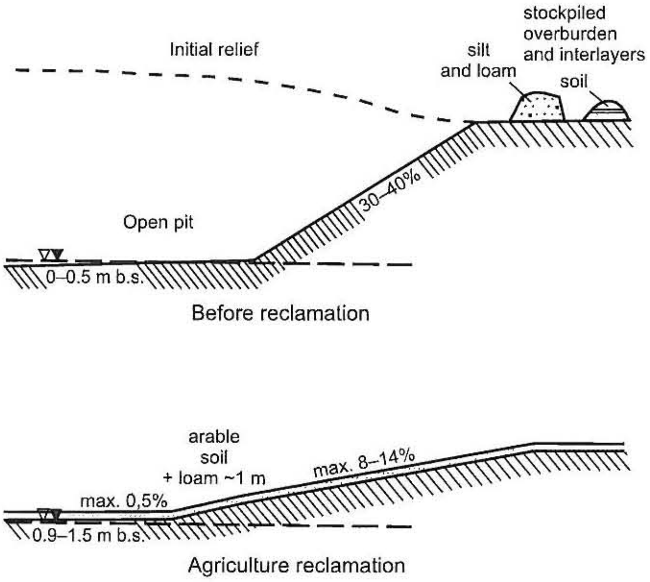

Fig. 10. Scheme of ground balance during technical reclamation of a pit for agriculture use

Note large amount of material to be displaced or imported for filling the pit; otherwise the pit area must be vastly extended.

tations for extending mine, and high costs of moving the ground may lead to mixed recultivation, e.g. agriculture and forestry. At high angle slopes, the access roads to the uppermost level, the rainwater drainage, irrigation and other engineering works as well as mechanised agriculture operations, and even introducing bush and trees, are difficult actions.

In the engineering practice, a suitable slope angle is calculated based on the physical ground properties such as grain size, cohesion, shear resistance, and pore water content. In dry climate, the slope could be steeper than in temperate zones. Permafrost and seasonally thawing frozen grounds may preclude durable shape of slopes. Terraced disposals comprising uppermost level and a set of shelves drained with trenches, divided by rather short escarpments as well as terraced inner slopes of quarries, are usually constructed before bio-reclamation.

Erosion processes both in productive soils and in subsoil rocks are greatly enhanced at steeply inclined slopes, larger catchment areas, and barren of vegetation. Early introduction of grass is the most widespread protective measure. It is sometimes supported by topsoiling, geotextiles, hydro-moulching, and the like. During storm rainfall, erosion rills and then gullies develop with concentration of runoff. Unfortunately, none of the current technologies is ideally suited for slope designing, particularly for slopes steeper than 1:5 (Southcott, 1997).

Gruszczyński, Trafas (1993) recognised slope angle (α) to be among three of the most important factors in the evaluation of mining waste suitability for bio-reclamation. The other two are: elementary physical properties of soil-forming materials and their thickness. This factor reduces suitability resulting from other factors, dividing it proportionally to the tangent (tg α), i.e. with an increase in inclination suitability of the same grounds is increasingly reduced.

CLIMATE AND EXPOSURE

Climate influences living organisms directly and indirectly through soil-forming processes, wind or rain erosion of soil, and water availability and quality. Each species may live, grow and reproduce within a certain range of solar radiation, precipitation, ambient temperature, and wind force.

Solar radiation is the motor force for photosynthesis and the land surface warming. Individual plant species differs in physiological needs of irradiation during day and night, and in different seasons. Some prefer sunlight, while other favour shadow.

Atmospheric precipitation is the main source of soil-contained water, indispensable to life, alongside with aquifers and food-contained water. However, the sum of annual precipitation (average) given in general climatic information is not sufficient to evaluate water availability to plants; both precipitation/evaporation balance fluctuates greatly during the year as well as seasonal needs of the plants. Saturation occurs when all the voids in the soil are completely filled with water. Although there is plenty of water available to plants at saturation, water uptake is seriously curtailed by lack of oxygen in soil at soil water contents greater than field capacity.

Only a fraction of water infiltrating to the ground is available to plants, depending on the share of capillary space (0.08–10 μm) which sucks water against gravitation forces. The maximum water content available to plants determines the field capacity of soil whereas the permanent wilting point

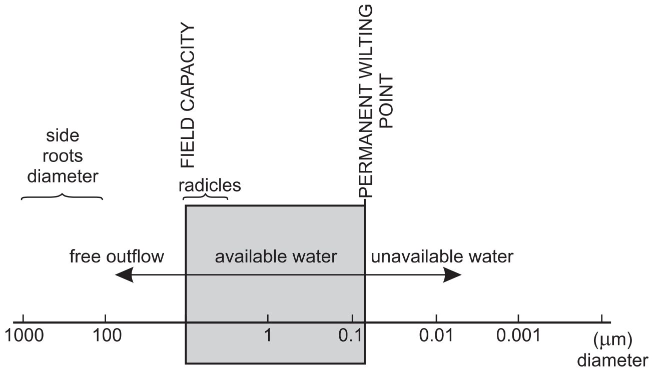

Fig. 11. Relation of water availability for plants to pore diameter in soils (Mackenzie *et al*., 1998)

(Fig. 11) denotes the soil moisture content, at which a plant will wilt and die not being able to extract sufficient water from soil to meet it's needs, due to high capillary forces and/or elevated osmotic pressure of saline solutions. At field capacity, all free water has been drained from the soil through gravity. Sandy soils may drain within a few hours but fine textured soils, such as clays, may take a few days to drain. Proper irrigation brings soil moisture up to field capacity.

Soil water storage capacity expresses the total amount of water that is stored in the soil within the plants, root zone. The soil texture (relative percentage of sand, silt and clay sized particles) and the plant rooting depth determine this. The deeper rooting depth means that there is a larger volume of water stored in the soil and, therefore, a larger water reservoir for the crop to draw up. Available soil moisture (defined also as available water storage capacity) is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point.

In dry climate, the potential evaporation and evapo-transpiration are greater than average precipitation, therefore dissolved salts concentrate in soils increasing greatly the osmotic pressure and alkalinity of the solution, then crystallising at the surface. Insufficiency of soil water results in development of halophytic biomes and generally low plant productivity per hectare.

Intensity of assimilation of solar energy by chlorophyll, efficiency of metabolism and water transpiration are highly dependent on ambient temperature. Vital functions of each species have also temperature limits and an optimal temperature range. The season when the day and night average temperatures rise above 5°C, free of ground freezing, and known as vegetation period for arable crops, changes with geographic location and indicates when bio-reclamation works can be carried out.

Exposition to strong and frequent winds is a negative factor. Transpiration from leaves increases then to dangerous levels, which is reflected in handicapped growth, deformations, smaller fruits, etc. However, moderate breeze is advantageous to life rhythm of plants and chlorophyll activity (Geominero, 1996).

Local topography and vegetation modify greatly general climate factor values. The key role is played by relief and inclination of slope, geographic orientation (Fig. 12), exposure, and covering plant density. Relief of surface mine workings and

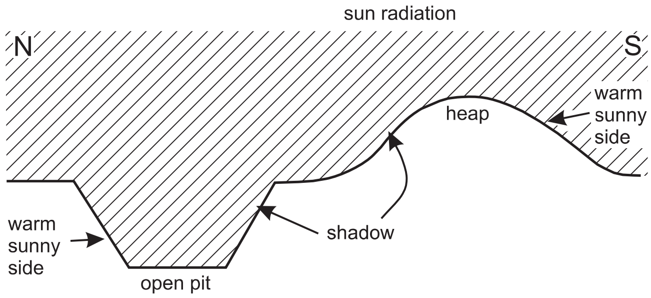

Fig. 12. Sun heated and shadowed slopes resulting from geographic orientation

post-mining areas is usually rough. At ridges, protruding sites and steep slopes soil is mechanically washed out which leads to permanent denudation of initial soils and subsoil hard rocks. Dissolved components and suspended colloids, which are nutritious to plants, are transported down slope. This results in excessive drying and depletion of elevated grounds while the pediment becomes enriched in moisture and nutrients. Within local depressions gley soils develop.

Geographic orientation combined with slope inclination is decisive for soil temperature. Soil surface temperatures during the day are significantly higher than those measured for meteorological purpose in the air 1 metre above the surface. In calm weather the difference may reach 10–15°C and even more, if the rocks are dark-coloured. The temperature is proportional to the amount of solar energy received, and this quantity is related to incidence of sun rays angle and the existence of dispersing factors like clouds, humidity, dust, plants, etc. The angle of incidence may increase or decrease with slope inclination (Fig. 13) and geographic orientation of the surface receiving solar energy (Table 12). The site latitude, plant cover and hours of the day are also decisive of yearly and daily soil temperature cycles (Fig. 14).

Exposure to sun and dominating winds is greatest at ridges and slopes of given orientation, whereas inside the open pits sheltered sites exist (Fig. 12). Many species find their ecological niches over there and spontaneous bio-reclamation begins. Local variations of climatic conditions are reflected in great

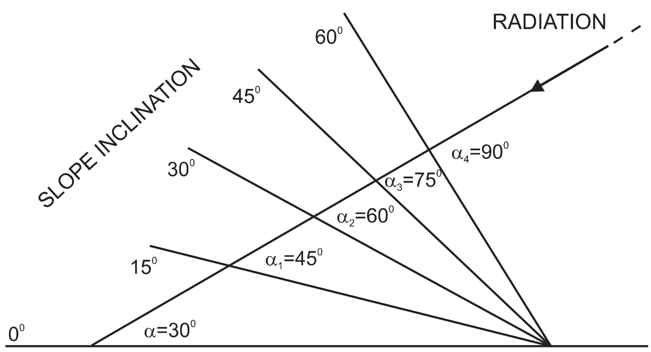

Fig. 13. Variation of the angle of incidence with increasing slope inclination

Table 12

Diversity of insolation at latitude 50°N at cloudless sky depending on slope angle and orientation (Total energy in monthly period in kcal/cm²)

Month	Slope inclination	Slope orientation towards					Difference between S and N slope
		N	NE, NW	E, W	SE, SW	S	
December	0	2.0	2.0	2.0	2.0	2.0	0.0
	10	0.7	1.2	2.0	3.0	3.5	2.8
	30	shadow	0.1	2.0	4.8	6.0	6.0
	90	shadow	shadow	1.4	5.7	8.3	8.3
March	0	8.8	8.8	8.8	8.8	8.8	0.0
	10	7.1	7.9	9.2	10.6	11.2	4.1
	30	2.1	4.6	8.7	12.6	14.1	12.0
	90	shadow	1.2	5.6	8.8	12.2	12.2
June	0	18.6	18.6	18.6	18.6	18.6	0.0
	10	17.8	18.1	18.7	19.4	19.5	1.7
	30	14.2	15.0	17.5	18.8	18.8	4.6
	90	2.0	5.4	8.8	8.0	7.0	5.0
September	0	10.8	10.8	10.8	10.8	10.8	0.0
	10	9.2	9.6	11.0	12.1	12.9	3.7
	30	3.9	6.3	10.6	13.8	15.4	11.5
	90	shadow	1.8	6.3	9.9	11.2	11.2

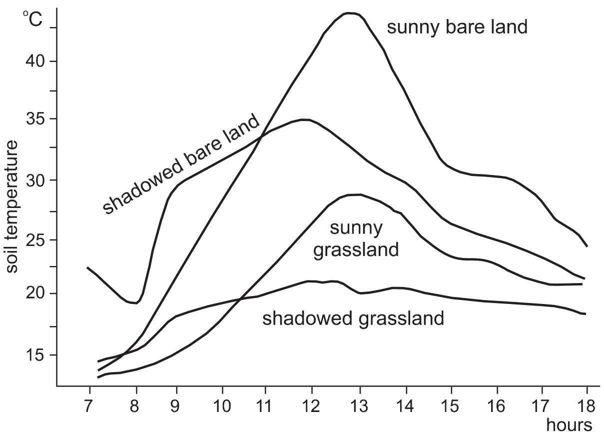

Fig. 14. Effect of the daily change of the angle of incidence and the vegetation cover on soil temperature (Geominero, 1996)

←

differences of reclamation effects frequently observed at the same geological substratum.

This short review, not touching soil parameters yet which are even more complicated, shows a multifunctional, complex character of natural conditions influencing bio-reclamation. There is an increasing interest in the application of ecological principles to the re-vegetation of abandoned mine workings by allowing natural colonisation and natural succession to proceed towards climax vegetation such as forests (Krzaklewski, 2001).

SOILS AND SOIL-FORMING MATERIALS

Post-mine terrains are covered by barren rocks of differing lithology and physical properties. As regards to their engineering and cultivate soil-forming properties, they are called grounds.

Understanding of soil matter properties and environmental performance is not uniform among scientists, and different classifications exist among pedologists and engineers collaborating in agriculture- and forest-directed reclamation. For example, there are two definitions of soil by the Soil Science Society of Amerika (www.soils.org):

"(i) The unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.

(ii) The unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and micro-organisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics".

I would add my own definition: "Soil is animate product of nature, resulting from decay and synthesis of minerals and organic matter, and their migration. Receives and supplies nutrient elements and water, protects seeds and plants from extreme temperatures. Produces differentiated biomass, food for animals and men, and alternative energy source”.

Producing abilities of soils are expressed in Poland in land-capability taxation classes (L-CT) and complexes of suitability for agriculture. They depend on:

- storage capacity in minerals (like nitrogen, phosphorus, potassium, sulphur, calcium) which is inherited from source rock and modified by agrotechnical means, and humus,
- fertility – the ability to transfer the nutrients to plants,
- crop capacity per hectare.

Dynamics of the soil-forming processes depend on climate (temperature, net balance of precipitation/evaporation), source rocks, relief, and vegetation type.

Initial ground layer thickness required for creation of biologically active soil (reclamation purpose) equals 0.2–0.3 m for grass, 0.5 m for crops, 0.6–2 m for forestry, depending of the species. Consequently, properties of the ground are investigated to the depth of 0.5 m for rising cereals, and 1.5 m for trees.

In the reclamation practice, any derelict site requiring soil reclamation is classified into:

- unsoiled ground terrain (in mine-workings, dump or clarifier), or
- degraded soil terrain, with the character of causative factor of the degradation given.

The causative factors could be

- hydrological: excessively dried or flooded with stagnant waters;
- chemical: acid, alkaline, saline; phytotoxically enriched; contaminated with WWA, PCB, heavy metals, etc.;
- mechanical: compaction.

Having these basic terms and notions in mind we shall find an answer to the question: what kind of grounds are favourable for soil-forming processes?

Two classifications are commonly used in Poland:

- by Skawina and Trafas (1971) — for grounds with the potential future use,
- by Krzaklewski (2001) — for neglected derelict sites, at least few years old.

T. Skawina and M. Trafas based their classification on stable properties, not changed by mining process and transportation. They distinguished 5 grades: A–E, which receive a reclamation (LB) index in the range of 0–100 points after determining only the four following properties of the ground:

- lithology (grain size), W_L (max. 60 points)
- calcium content (as $CaCO_3$), W_{Ca} (max. 15 points)
- physical sorption (methylene blue), W_{so} (max. 15 points)
- cohesion, W_{sp} (max. 10 points)

LB is calculated as a sum $LB = W_L + W_{Ca} + W_{so} + W_{sp}$
$LB\ max = 100$

W_L index based on USDA soil science classification[1] (equivalent of geotechnical grounds classification in Poland; borderline grain diameter clay/dust equals 0.002 mm, and dust/sand 0.05 mm, Fig. 15) we calculate:

W_L = clay % + 0.5 dust % for grounds below 20% clay, and
W_L = 20% + 05 dust % for grounds above 20% clay

easily finding out that the maximum number $W_L = 60$ is achieved at 20% clay + 80% dust

W_{Ca} index depends on $CaCO_3$ content of the ground reaching maximum value of 15 points for 5–10% $CaCO_3$, and 10 points for 3–5% and 10–20% $CaCO_3$.

W_{so} index rises proportionally:
from 0 for values of methylene blue sorption capacity of <3 mval/100 g of ground,
up to 15 for the capacity of >15 mval/100 g of ground.

W_{sp} index is related to easily determined plasticity index. It reaches maximum value of 10 for the plasticity range of 6–12%.

The sum LB is placed into the following classification scheme of the reclaimed grounds:

>75 points – quality A grounds
51–75 points – quality B grounds
21–50 points – quality C grounds
<21 points – quality D grounds

Grounds which are toxic are placed into class E grounds.

The grounds toxicity is connected with the increased content of sulphur, sulphides, heavy metals (As, Cd, Cu, Pb, Zn),

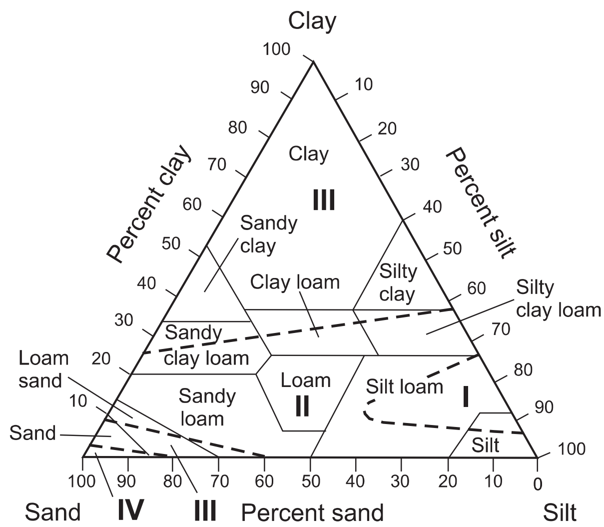

Fig. 15. Reclamation suitability categories of grounds I–IV (Chwastek, Żuławski, 1981) against USDA soil science classification (Sara, 2003)

Reclamation suitability categories are based on soil-forming activity, depending purely on lithology of grounds. I – highly suitable, II – active soil-forming processes, easy reclamation, III – moderate soil-forming processes but bio-reclamation difficult, IV – very slow soil-forming processes, not suitable for reclamation.

[1] There are many soil classification schemes (Sara, 2003) and even in one country nomenclature of soil types differs greatly; e.g. borderline of sand and silt in USDA and MIT schemes is 0.05 mm, in USCS scheme — 0.067 mm, in ASTM scheme — 0.075 mm, and in FAA scheme — 0.04 mm, and borderline of clay and silt in the same schemes is 0.002 (USDA & MIT), not recognised (USCS), and 0.0045 (ASTM & FAA). Therefore, caution is necessary when applying purely word based soil terminology without size distribution curves.

and soluble Al salts, total salts, thermal sensitivity, pH <3.5, (KCl), <4 (H_2O), and >8 (KCl, H_2O), hydrocarbons, or increased radioactivity.

Management issue of this classification is as follows:

Quality A — assures great suitability for agriculture reclamation;

Quality B — suggests small suitability for agriculture reclamation but great suitability for forestry;

Quality C — denotes defective soils, not acceptable for agriculture but suitable for forestry if improved;

Quality D — are barren grounds, not acceptable for reclamation, requiring isolation or fertilizers;

Quality E — toxic grounds, not acceptable for reclamation, requiring neutralisation and isolation.

Other considered physical properties include:

- stone content,
- specific density SD (natural soils: 2.5–2.8, exceptionally organic-rich soils: 1.55–2.4),
- volume density VD (0.9–2.1),
- SD:VD = porosity index; low porosity signalises compaction, which can be undesirable side effect of using heavy machinery,
- plasticity index,
- permeability coefficient,
- lithology, especially in the case of toxic elements; e.g. sulphur and sulphide forms are toxic at the content level of 0.02% in pure sand but of 0.07–0.1% in clays, and more than 1% in marly clays, because of their $CaCO_3$ content.

Chemical properties considered in detail (and included in the quality assessment — toxic grounds) are:

- pH (sensitive to some plant species, costly neutralisation),
- salinity (e.g. SAR index; SAR = $Na/0.5(Ca+Mg)^{1/2}$; if increased >10, implies costly neutralisation),
- heavy metals,
- nutrients.

Important physical and chemical factors influencing usefulness for agriculture are given in Table 11.

CULTIVATION REQUIREMENTS

Usually long time is required for transforming barren ground into productive soil, for improving its fertility, and for establishing a target: arable fields or forest succession. Suitable temperature at the ground surface, humidity, aeration, chemistry, and access to nutrients enhance soil-forming process. Addition of imported or properly stored topsoil (from the careful removal before opening the mine), fertilising, introducing grass and leguminous plants, planting and replacing pioneering species, ploughing, and other technical and cultivating operations consume funds and give highly diverse results. Finally, desirable species can be introduced.

Soil temperature and humidity is controlled by climatic and microclimatic conditions, the letter related to the slope exposition (Table 12, Fig.12), and developing system of plants, which differ greatly in evapo-transpiration of water.

Proper soil aeration is necessary for life of micro-organisms, sprouting, growth of higher plants radices, chemical redox processes, and absorption of nutrients. The aeration depends on soil porosity, texture, and organic matter content. Compaction which reduces porosity and water permeability, has negative influence on cultivation but prevents soil erosion at early stages of slope forming process.

Certain chemical elements in soil are necessary as nutrients for plants. The macro-nutrients are: N, K, Ca, Mg, P, and S. They are found in plants in concentrations of 0.1–2% but their satisfactory level in soil solution is considered at 30–200 ppm. Nutrient deficiency inhibits growth and provokes deformations. Some elements, e.g. phosphorus, are present mostly in insoluble, and therefore unavailable forms. Aluminium and iron can be mobilised in very acid soils (pH <4), and appear excessive, and thus toxic. Indispensable micro-nutrients present in plants are: Fe and Mn — about 100 ppm, B and Zn — about 10 ppm, and Mo — 0.1 ppm. Post mining grounds are always very poor in nitrogen, therefore nitrofilous plants are sown at initial stages of re-vegetation.

Many plant species are sensitive to pH of groundwater and soil-forming material, in effect placing them on reclaimed waste heap can be difficult. The wastes deposited within the Upper Silesia mining district of Poland differ from one landfill to another depending on the industry branch or even on the enterprise. For example, coal mining wastes frequently release acid solutions, whereas coal fuelled power plants deposit fly ash of basic and alkaline character. If both wastes are co-deposited, a desirable synergistic effect can be expected: neutralisation, nutrient supply, improved water retention, decreased deflation and slope erosion, and shortened reclamation cycle (Strzyszcz, 2003). There are many advantages but also inconveniences of plant reintroduction there (Table 13).

Redevelopment of post-mining terrain is aimed, in the most cases, at reshaping and introducing plant cover, different from that existing prior to exploitation. Selection of new plants depends on the expected utility and cultivation requirements both in the short and long prospect. Trees are frequently designed as masking curtains and landscape decoration. Table 14 gives a guide to species suitable for the most frequent uses, and Table 15 — the constraints in choosing sowing and planting methods.

Rate of spontaneous re-vegetation and establishment of plant species depends on the environment habitats. The proximal environment supplies pollens and seeds by the wind, whereas additional distal import is provided by birds and mammals. Skilled man-managed reclamation allows introducing autochtonous vegetation much quicker than the spontaneous return of flora and fauna on barren ground and waste could take place. However, harmonisation of both processes is necessary.

Re-vegetated plots form automatically habitats for fauna which will find ecological niches there. However, effective restoration potential of fauna is more difficult to assess. The potential is sensible to variety of factors like topography and vegetation, their diversification and stratification of plants (herbs, bush, trees), wetlands, noise and even early spreading of stored soil, which is rich in worms and in-

Table 13

Advantages and inconveniences of plant reintroduction (Williamson, Bradshaw, 1982)

Advantage	Inconvenience
Establishing self-supporting community	Autochtonous species may be deficient and hardly available to seed or plant seedlings
Plants well adopted to local climate. Irrigation indispensable only in early stage	Storage and sprouting of autochtonous species need supervising by experts
Plants may quickly adapt to low fertility soils and give early crops or pasture	Slowly growing herbaceous plants, some shrub and trees may delay expected productivity
Harmony of rehabilitated plots with surrounding landscape	If newly formed soils differ from previous one reintroduction of autochtonous species may be difficult
Animals will recolonise the plots. Animal wildlife habitats can be the final use of the post-mining area	Probability of gaining profits from agriculture crops or animal farming is rather low

Table 14

Plants required for different reclamation targets (Williamson, Bradshaw, 1982)

Land end-use	Type of plants
Pastures	Grasses and herbs
Agriculture	Cereals and other arable plants guaranting rapid growth and good crops
Fauna habitat	Variety of autochtonous and naturalised species which accept the reclaimed site, will supply seeds and diversify ecosystem
Original use, revegetation of plots	Autochtonous species effective in production of timber and/or food for animals, some easily regenerating after wood fires
Recreation	Tolerant species of low productivity, resistant to trampling

Table 15

Constraints for choosing sowing and planting methods (after Geominero, 1996, transformed)

Factor	Sowing				Planting	
	throw	in rows	hydro	aeroplane	manual	mecha-nised
Slope inclination	×(<20°)	×(<15°)	–	–	–	×
Area	–	–	–	×(>10 ha)	×	–
Precipitation	××	×	××	×	–	×
Field humidity	×	×	×	×	–	–
Stone/solid rock content	×	×	–	–	–	××
Soil compaction	××	×	××	–	×	××
Access to plot	×	×	×	–	×	×
Water availability	–	–	××	××	–	–
Specialised techniques	–	–	–	–	×	×
Cost	×	×	×	×	×	×

– not limiting, × moderately constraining, ×× strongly constraining sects. In other words, the diversity of habitats, niches, potential nesting places, even if artificially created, increases chances of successful restoration. The variety of bird species observed indicates the level of success achieved.

The current reclamation techniques, used in order to get a quick „greening" effect, are not always successful. The result of forced management is short lasting and often expensive. At the same time, ecologists turn our attention to native, anemochorous, heliophilous, and expansive species that enter post-mining ground by the spontaneous succession and appear to be resistant to this hostile environment. There are many examples of elevated bio-diversity of wasteland communities and even of protected plant and animal species. A natural-biological restoration is postulated, then.

Having in view quite complicated assessment of conditions controlling reclamation of a certain land plot, Krzaklewski (2001) has proposed an alternative, simple method. It consists of biological observation of spontaneous plant succession on a derelict site under study. If the time of ground exposure (TE) and the share of newly vegetated site in the total area (S%) are known, it is easy to place any site into the categories I–III of bio-reclamation potential:

I — S almost nil (if TE ≥ 10 years), overgrowing very slowly → bio-reclamation very difficult

II — S insignificant within the first 5 years, overgrowing slowly → bio-reclamation difficult

III — S high, overgrowing starts in the 1st or 2nd year → bio-reclamation easy.

GROUND INSTABILITY AND POLLUTION

Unstable grounds, apart from naturally generated in certain relief, climate and geological conditions, result from underground mining. When minerals are mined out, the unsupported roof rocks collapse causing subsidence or collapse at the surface. This process affects buildings, roads, water supply, drainage systems, and other infrastructure. Natural drainage system is also severely affected. Discontinuous deformations are the most important; they develop over shallow mine works situated not deeper than 50–80 m from the surface.

When the underground mining ceased, the degradation on the surface remains and may develop in the next years as well. In flooded salt mines, dissolution and collapse continue for decades or even centuries. In the Upper Silesia, 35% deformations above mine cavities have developed during the first 25-year period (Goszcz, 2001).

In Poland, degraded surface is typical for all underground mines, being the most extensive in the Upper Silesia (hard coal, lead and zinc ores), Lower Silesia (hard coal), Wapno, Wieliczka-Barycz and Łężkowice (salt), Grzybów and Jeziórko (native sulphur), and Rudki (pyrite) areas. In the Upper Silesian Coal Basin, the subsided areas reach 300 km^2, sinking locally more than 20 m; some 400 ha of forests were degraded and elsewhere some 150 km^2 of usable land are considered susceptible to collapse (Goszcz, 2001).

Considering great risk of construction on such terrain, the following measures are taken successively:

— delineation of risky ground based on the mine maps,
— calculation of the critical depth of mine chambers,
— localisation of the planned investment,
— geophysical survey (electric, microgravimetry) for voids location and programming boreholes,
— drilling holes and processing results,
— filling empty spaces.

This is a costly process and success could not be taken for granted. Therefore, attempts are made to prepare maps classifying geotechnical hazards on mining terrain and to manage land use of such terrain with some restrictions. E.g. Bromek *et. al.* (2001) distinguished three, Goszcz (2001) four, and Lejczak (1969), Popiołek, Ostrowski (2001) even more construction ground categories (Table 16, Fig. 16).

A pressure grows to utilise all available inner city areas for constructions, even the old landfills. If not seriously contaminated, the landfill grounds could presently be considered for compaction, penetration grouting or other geotechnical improvement. Construction on landfills is risky, especially in the situation when the history of their formation and structure is unknown and compaction was not performed. Subsiding results in depressions which might limit the future land use.

Site investigations of landfills and other derelict land include site history, surface imaging techniques, sampling and *in situ* testing, determination of geotechnical properties of waste (density, shear strength, modulus of compressibility, and hydraulic conductivity), and applicability assessment of the known ground modification technologies (Thom, Hausmann, 1997; Sara, 2003). Extreme caution is advised in using any data presented in experimental papers and case studies, and received from few specimens, because of the variability of waste streams dumped and, hence, their geotechnical properties. Monitoring and recording of the landfill history may help resolve the problem.

Spontaneous ignition of coal-waste dumps (containing even as little as 5% of high ash pyritic coal), which is typical for colliery districts, could be avoided by improved insulation from atmospheric air or exploiting the dump material for some less demanding ground constructions.

Any use of mining degraded areas requires careful inventory of environmental impacts and detailed maps depicting:

- mining and accompanying industrial areas, constructions (like waste dumps, settling ponds, clarifiers), and geotechnical ground types,
- ground subsidence (current and anticipated), and flooding risk areas,
- areas of shallow exploitation susceptible to discontinuous deformation, position of shafts, inclines, galleries, and chambers.

Construction of large water ponds and reservoirs on post-mining terrain needs improved EIA procedures.

Table 16

Construction ground suitability categories in mining terrain (Lejczak, 1969, modified)
(Terrains highly endangered by discontinuous deformations are not classified here)

Category	Constructional suitability	Expected deformation		
		T_{max}*	ε_{max}*	R_{min}**
0	suitable even for susceptible constructions	0.5	0.3	40
I	suitable; protection of constructions not necessary, only minor damage observed but can stand the test of time	2.5	1.5	20
II	slightly risky; minor damage easy to repair possible, protection of all construction not economic	5.0	3.0	12
III	risky; some protection of constructions reasonable	10.0	6.0	6
IV	severely risky; important (costly) protection necessary	15.0	9.0	4
V	not suitable for construction	>15	>9	<4

* less than [mm/m], except the V category, T– inclination, ε – horizontal distortion
** R – curvature radius, more than [km], except the V category

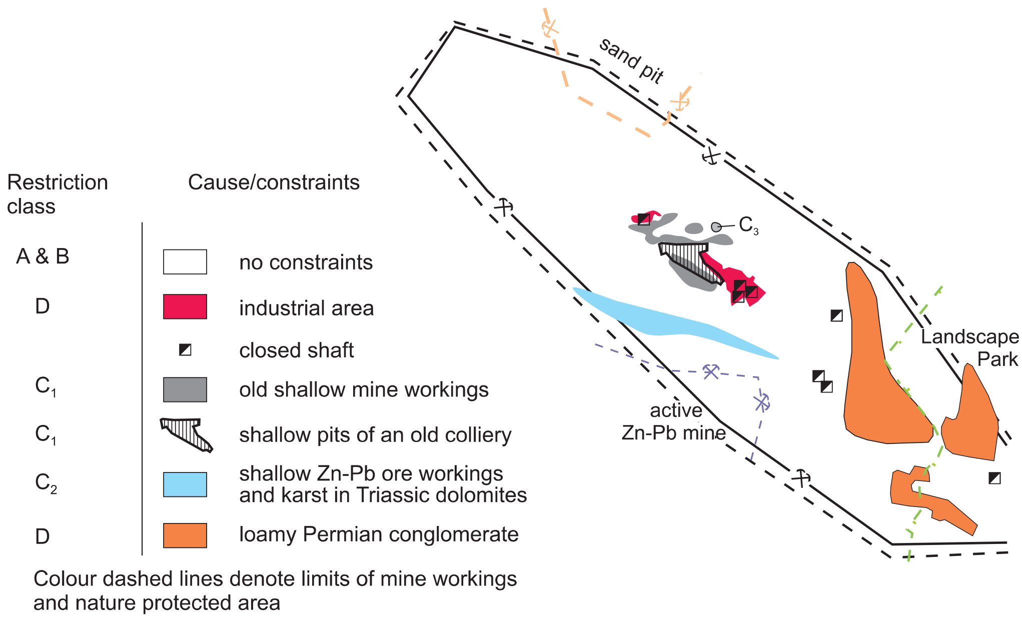

Fig. 16. Example of construction ground categorisation of an old mining area, Siersza, Poland (Popiołek, Ostrowski, 2001)

CONCLUSIONS

1. Vast post-mining areas appear to be a real challenge to sustainable development in Poland. Their reclamation is foreseen in government policy programmes but local authorities are not sufficiently prepared yet to assess land suitability for future use and to control if the executed reclamation has been proper and sufficient.

2. A sustainable development concept provides that the region depleted of mineral reserves should eventually become enriched not only by charging mining rent but also by establishing in a post-mining area new land-use forms generating profit or by natural succession parks improving environment quality.

3. Properly prepared mining project should cover a whole mining cycle, from opening the mine to its closure, including land reclamation/redevelopment. The technical reclamation stage, consuming major part of the expenditures, can be performed by the mine itself.

4. The cash-flow analysis of a mining project should internalise cost of turning brownfields into vital community assets. Reclamation fund shall be created.

5. Different sets of natural conditions control each of the post-mining terrain potential uses. Its development into ecosystem-dominated land uses is controlled by a number of factors including water conditions, slope and erosion, microclimatic indicators, soils and soil-forming materials, cultivation requirements and/or spontaneous plant succession. The ability of a site to achieve a construction land end-use depends essentially on the ground stability and pollution. Living environment plays in this case subordinate role.

6. Ecological approach into qualifying bio-reclamation potential of a post-mining plot on the basis of the observed natural succession of plants is simple and cheap, however, applicable only to derelict sites abandoned years ago. In the land-use planning practice, the assessment of land suitability for certain use should be performed before making a decision on mine development.

7. Construction on the mined terrain and the landfills has been largely avoided until recently because of the plethora of hazards. A new perspective is opened for turning brownfields into community assets by mapping and classifying geotechnical hazard on mining terrain in accordance with improved EIA procedures, and introducing some restrictions on land use management.

8. There is a large field for cooperation between geologists, mining engineers, pedologists, ecologists, agri- and sylviculturalists, toxicologists, and landscape architects in redeveloping post-mining areas.

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