Geotechnical investigations of different geological landscapes for the purposes of remediation of municipal landfill sites

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Abstracts: Activities related to construction of new landfill sites, as well as remediation and re-cultivation of the existing ones on the territory of Serbia, have intensified in the past few years. In relation to this, complex research has been conducted to determine natural geological properties of the terrain and its suitability for the proposed construction works and possible environmental pollution. However, during the planning stages of constructions, which are there for Eco-system protection, little attention is paid to geological foundations, which can themselves produce certain ecological consequences. Few cities and towns in Serbia can boast a tidy and well-planned landfill site. In Serbia, apart from 180 official landfill sites, there are hundreds of "unlicensed" ones that have been formed without any analysis of location suitability – the analysis would have included certain geotechnical, geo-engineering, hydro geological and ecological studies. That is the reason why, in most people's minds, an ecological landfill site is the same as an unlicensed one, and they invariably have negative responses to the proposed construction of a new landfill site near inhabited areas. The deep-ingrained habits of depositing waste directly onto the surface and close to the inhabited areas do not help the cause. This is very prominent on the alluvial terrains that are close to the riverbeds – the kind of terrain most often used in the unlicensed landfill sites (i.e.: stagnant waters, dried waterbeds or natural depressions).

Until now, during the construction of new landfill sites and the existence of the current ones, the following problems have been noted to recur:

- Water resistance of the terrain under the main body of the landfill, characteristically of alluvial terrains.
- Stability of hillsides, characteristical for hilly terrains.

This paper presents brief review of several characteristical examples of landfill sites locations already processed during the investigations in different geological environments.

Résumé: les Activités sont relaté à la construction de nouveaux sites de landfill, de même que le redressement et recultivation de l'une existante sur le territoire de Serbie, a intensifié dans le passé peu d'années. Par rapport à ceci, la recherche complexe a été dirigée pour déterminer des propriétés géologiques naturelles du terrain et son aptitude pour les travaux de construction proposés et la pollution écologique possible. Cependant, pendant les étapes de planification de constructions, qui sont là-bas pour la protection d'Ecosystème, la petite attention est payée aux fondations géologiques, qui peuvent produire alors de certaines conséquences écologiques. Peu de villes et les villes dans Serbie peuvent vanter un site de décharge rangé et bien planifié. Dans la Serbie, en dehors de 180 sites de décharge officiels, il y a des centaines de "non autorisé" l'une qui a été formée sans n'importe quelle analyse d'aptitude d'emplacement – l'analyse qui aurait inclus certain geotechnical, la geo-ingénierie, la sanitaire études géologiques et écologiques. Cela est la raison pourquoi, dans les esprits de la plupart des gens, un site de décharge écologique est pareil comme un non autorisé l'un, et ils ont immanquablement des réponses négatives à la construction proposée d'un nouveau site de décharge près des secteurs habités. Les habitudes profond imprégnés de déposer de gaspillage directement sur la surface et proche aux secteurs habités n'aide pas la cause. Ceci est très éminent sur les terrains alluviaux qui sont proches aux lits de fleuve – le genre de terrain le plus souvent utilisé dans les sites de décharge non autorisés (les eaux stagnantes, les matelas d'eau séchés ou les dépressions naturelles).

Jusqu'à présent, pendant la construction de nouveaux sites de décharge et l'existence de l'une actuelle, les problèmes suivants ont été notés pour se reproduire :

- la résistance d'eau du terrain sous le corps principal de la décharge, caractéristiquement pour les terrains alluviaux.
- la stabilité de flancs de coteau, characteristical pour les terrains vallonnés.

Ce papier présent la revue brève de plusieurs exemples de characteristical d'emplacements de sites de décharge a traité déjà pendant les investigations dans les environnements géologiques différents.

Keywords: geotechnical engineering, hydrogeology, pollution, waste disposal

INTRODUCTION

One of the basic principles of the European Convention is the protection, conservation and improvement of the environment. Respecting this principle is of utmost importance for countries in transition periods, such as Serbia and Montenegro: the Guidelines of the European Union Commission [5] which regulate this area, are binding for all member states.

In Serbia, 60-70% of municipal waste is collected (around 2.2 million tonnes). Collection is arranged in towns and cities only. In rural areas collection doesn't exist (waste is mainly deposited close to the streams, rivers, abandoned or

unused agricultural fields, and is often burnt). An average citizen of Serbia generates around 290kg of waste per year. Most of the municipal waste (around 63%) is produced by the households, while 20% is generated as commercial waste [1].

There are few towns in Serbia that can boast a planned municipal landfill site. At this moment, apart from 180 official landfill sites, there are hundreds of "unlicensed" ones, formed without any analysis of the location's suitability, including certain geotechnical, hydro-geological and geo-environmental investigations. Unfortunately, most of the official landfill sites are still un-planned and un-maintained and they endanger the environment in different ways. As a result of gathered data, it has been concluded that the existing locations for waste disposal can be divided into four categories (table 1) [6].

Table 1. Categorisation of Waste Disposal Locations

Category	Characteristics
K - 1	Large hygienic landfill sites that are fully equipped (with drainage systems, foil underlay and monitoring systems for the control of filtrates and gases emissions). Built or under construction are 6 such landfill sites.
K - 2	Official landfill sites which can be used during a long period, under the condition that they are remediated and made good – cultivated and landscaped according to the European standards. In Serbia, there are 7 such landfill sites.
K - 3	Official landfill sites – waste disposal sites that can be used for another five years, conditioned on remediation with minimal protective measures. There are 51 sites like this in Serbia
K - 4	Official landfill sites – waste disposal sites that don't fulfil even the minimal protection requirements, that are full to capacity and that need to enter the remediation and re-cultivation process.

Characteristic examples of category K-4 sites are: the landfill site in Paracin, located in an alluvial plane of Velika Morava river, very close to the artificial lake, which is arranged (in part) and used as public lido; the landfill site in Obrenovac – located in an alluvial plane of river Kolubara (in the parish of Belo Polje village); the landfill site in Vlasotince which is located just 800meters from the town, immediately next to river Vlasina, and many others (including Cacak, Aleksinac, Pancevo, Bela Palanka, Uzice, Gornji Milanovac). Lately, there has been some cleansing and re-cultivation work done, as well as relocation or closure of certain sites. Typical landfill sites that have had work similar to that already done, or are in the process of having it done, are: Subotica (Palic), Belgrade (Batajnica), Arandjelovac, Smederevska Palanka, Leskovac, Novi Pazar and others.

Preliminary results of the analysis of the territory of Serbia completed so far, starting from the regions presented in this paper and the analysis of the key characteristics of open spaces in Serbia, show that it is possible, through constructing 29 regional landfill sites and 44 transfer stations, to form a rational network for collecting, transportation and depositing municipal solid waste, which would significantly speed up the process of resolving this problem [6].

SHORT REFLECTION ON CHOOSING THE LOCATION FOR A LANDFILL SITE

In most people's minds, an ecological landfill site is the same as an "unlicensed" one. Most people's reaction to a proposal for construction of a new planned site near habitation is negative. Problems of a geotechnical and hydro-geological nature are often compounded by the unwillingness of the users (public communal companies) of the problematic and uncultivated sites to incur higher expenses associated with the use of fully investigated and planned new sites. This often prejudices rulings and permissions against detailed investigations. Public communal companies and other users do not want to stop using existing locations even though, from a geological aspect, these can be very unsatisfactory, often making any sanitary controls inefficient. In the designing, planning and development of constructions with environmentally friendly functions (hygienic landfill sites and especially dangerous materials waste disposal grounds), the importance of the geological basis and foundations is sometimes overlooked, which in turn can lead to unsatisfactory ecological consequences.

To solve these problems, and depending on the particular problems and conditions of the terrain, it is necessary to apply appropriate geotechnical and hydro-geological investigations. The correct choice of locations suitable for waste disposal of any type has to be based on a comprehensive overview of all relevant factors to reach the best solution. The underlying factors for making this possible are investigations into:

- Morphology and lithogical – stratigraphic composition of terrain
- Hydrographic situation (rivers, streams, wells, springs, water courses)
- Meteorological characteristics such as: temperature characteristics of the location; wind directional patterns; type, frequency and speed of wind
- Existing road network and the possibility of building access roads
- Underground water's levels
- Mechanical characteristics of the underlying soil (acceptable hardness and deformity levels – considering that, most often, in the design of a landfill site there is a provision for adequate outbuildings, or, within the site or over it – embankments of certain height will be constructed)
- Hydraulic conductivity of the ground and surrounding area (saturation level, contamination susceptibility, filtration and self-cleansing capacity)
- Estimate of natural risks (terrain stability and the possibility of land slide appearance, the possibility of flooding, seismic properties of the terrain, etc) and

- Regenerabilty of the existing resources

Apart from needing necessary geological foundations to enable the choosing of locations for new landfill sites, determining the geotechnical and hydro-geological conditions of the terrain is also necessary for defining:

- Conditions for building (constructing), landscaping and maintaining of a new municipal waste disposal site
- Conditions for sanitory and remedial works on an existing municipal waste disposal site
- Conditions for closure, that is to say re-cultivating a municipal waste disposal site

TYPICAL LOCATION'S ANALYSIS

The usual practice in Serbia is for the waste to be disposed on the surface, mostly on the outskirts of the conurbation. This practice is very noticeable on alluvial terrain, normally found near rivers, where the "unlicensed" waste disposal grounds are most often formed in a variety of stagnant waters, dried water beds or natural depressions. Alluvial terrains are mostly composed of sand and gravel on a bed of impermeable clay (clay, marls, solid rock mass). Considering the thinness of the overlying layer, mostly made of dusty sands and sandy clays, it is possible for the polluted water to rapidly seep through to contaminate underground water supplies. This leads to degradation of groundwater quality that limits its usage. This presents a real danger to the living environment as, apart from polluting underground waters, it threatens surface waters. According to the European Union guidelines, outside limits for conductivity values for the bedrock are $K_f = 10^{-9}$ m/s, which clearly leads to the conclusion that the landfill sites must be located exclusively on impermeable ground, with a layer thick enough to prevent the communication of contaminated water with the underground water. The terrains of southern Banat, made out of quaternary fluvial, Eolian, Eolian-aquatic sediment deposits, provide few possibilities for a municipal waste disposal site, in respect of hydro-geological conditions. With rolling-hilly landscapes, mostly dominated by clay-marls sediments, the watertable is deeper, thus presenting more of an obstacle for contamination of underground water resources. In some cases, landfill sites are located on a hard rock mass, presenting a specific problem of fractures and the stability of hillsides. Deserted open-cast mines in close proximity of mining towns and villages often present sites for waste disposal without any ground preparation, which leads to ruined landscapes, contamination of underground waters and degradation of soil: there are rare examples of recultivation of such sites. In the last few years releases of toxic matters from factories into the open rivers have led to the erradication of fish stock, and even to contamination of the underground waters in the vicinity.

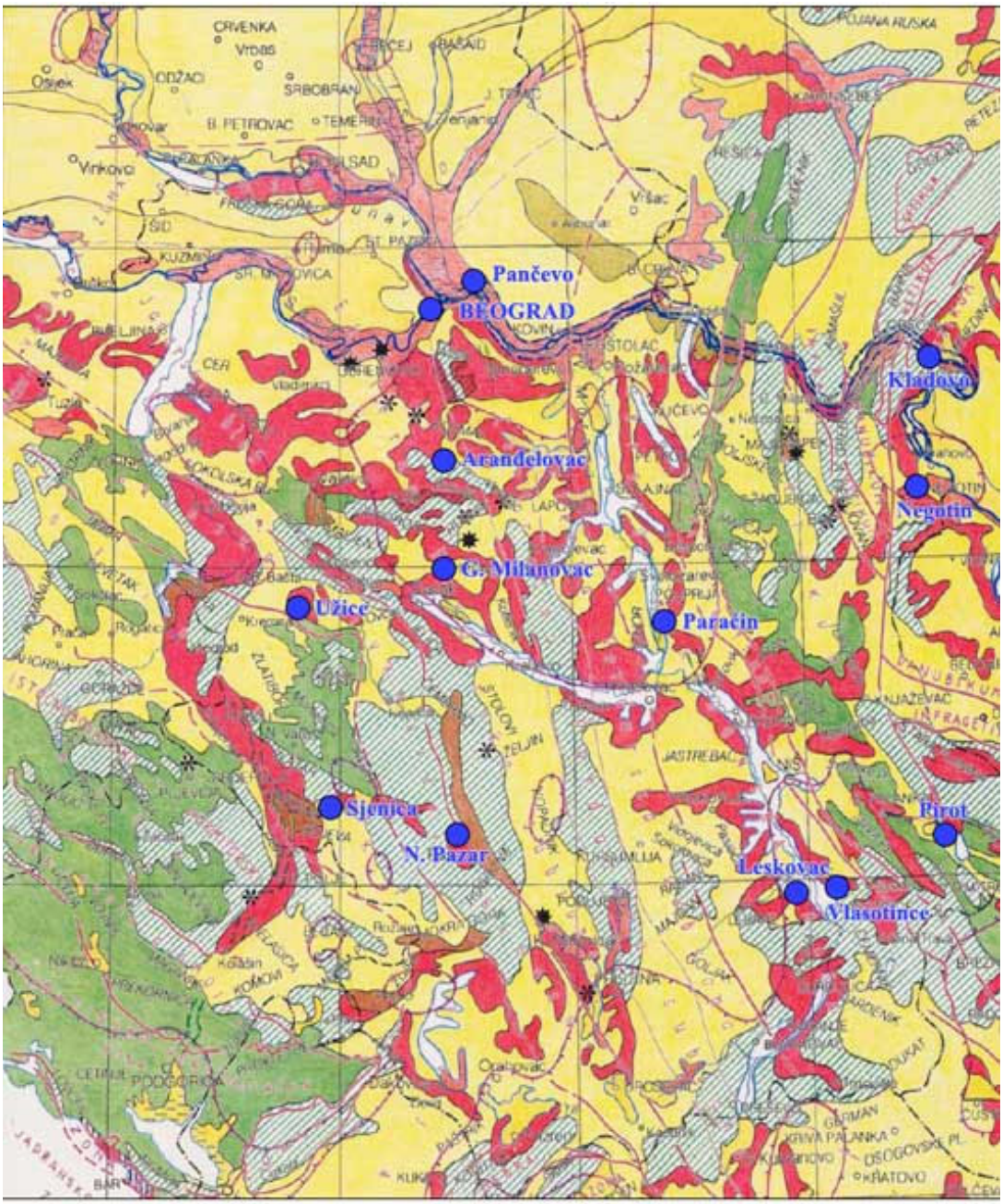
Basic criteria for choosing a typical location are geotechnical and hydro-geological conditions – different geological surroundings. Picture 1 shows a map of the terrain according to the engineer-geological acceptability. The map contains the features of important elements characterising the territory of Serbia in respect of geotechnical limitations, such as:

- Compressibility – according to which there is a separation of marshy and silt terrains of great and medium compressibility,
- Terrain instability in respect of landslides and rockfalls, characteristic of Neogene sediments as well as older, incompletely hardened, and very fractured and altered rock masses,
- Erodability of non-cohesive, loosely cohesive and altered rocks,
- Fluvial erosion and flooding alongside unregulated river flows,
- Aeolian processes in exposed parts of sandstones and
- Karst processes in limestone terrains.

The map also features important unfavourable tectonic influences on the terrain, as well as the zones of higher seismic risks. Outside of these outlined zones are the terrains of favourable geotechnical characteristics.

The following examples describe locations with site selection reflecting differing levels of critical approaches, scope and methods used to conduct the investigations.

Vlasotince (K – 4) – The existing landfill site is badly located, immediately along the right valley side of Vlasina's riverbed, around 800 meters downriver from the town. The main body of the landfill site is threatened by the river's current, especially during the active torrents – influenced by the flooding waves. The foundation of the main body of the site is an alluvial-sediment complex which has problematic hydro-geological and geotechnical characteristics. The alluvial groundwater is exposed to pollution by draining contaminated water from the main body of the landfill site. Overlying dusty-sand clays, according to the data about the filtration capabilities, do not represent completely impermeable surroundings, meaning that the base of the landfill site is unsatisfactory. Considering that the landfill site has been used for many years without any prior analysis of the locality's suitability (dependant on the criteria for the choice of locations), this particular site has all the characteristics of an unplanned, uncultivated dumping ground. It is suffering from rubbish dispersion and draining of the contaminated water that filters into the ground and surface waters of river Vlasina.



THE MAP OF ENGINEERING-GEOLOGICAL FAVOURABILITY

UNFAVOURABLE ENGINEERING-GEOLOGICAL CHARACTERISTICS OF TERRAIN

- **Compresibility** — a) very high; b) medium
- **Unstability** — a) sliding; b) rock falling
- **Erodbility** — a) erosion of slopes; b) area of fluvial erosion
- **Abrasion**
- **Eolian processes**
- **Intensive karst**
- **Swampy terrain**
- **Terrains with relatively suitable engineering-geological characteristics**

Zones of increased seizmic risk (> 8° MCS)

UNFAVOURABLE TECHNOGENIC INFLUENCES ON TERRAIN

Trafic corridors | **Storage basins** | **Mining activities** | **Mining and industrial waste dumps** | **Location waste disposal**

Figure 1. The map of the terrain according to its engineer-geological favourability (Geological Atlas of Serbia – group of authors)

Figure 2. Municipal waste disposal ground for the town of Vlasotince (photo: D. Rakic, 2004)

Paracin (K – 4) – Municipal waste disposal site for the town of Paracin – "Buljanka" has been formed in an old dried waterbed of Velika Morava river, on a terrain consisting of alluvial sediment such as: dusty-sand clay, sands and gravel. Considering good water conductivity of alluvial-sediment complex, it is obvious that the contamination factor is directed towards the waters of the artificial lake, as well as the river itself. Precisely because of the particularly disordered and badly located landfill site with no prior analysis and investigations, it has been suggested to move the landfill site to another location.

Figure 3. Town landfill site for the use of the town of Paracin (photo: M. Rakijas 2002)

Kladovo (K – 4) – The location of the new municipal solid waste disposal site – Jakomir B, is to the south-west of the town, around 4.5 kilometres away. It is situated in a ravine that is naturally oriented towards the Danube. In relation to the village of Milutinovac, the landfill site is about 3.5 kilometres. The terrain is made up of Neogene and quaternary lake-alluvial sediments of the Danube's key. The base of the ravine itself is built of Pliocene lake sediments (dusty and marls clay, dusty-gravel sands and dusty sands and gravel). The presence of a significant percentage of clay fractions in sands and gravel greatly reduces their water-permeability, even though the lake dusty clay has a far smaller filtration quotient, which allows it to be used as an isolator.

Pancevo (K – 4) – A relatively suitable location has been chosen for the construction of landfill site in the area around Pancevo, based upon the condition of undertaking measures for complete hydro-insulation of the foundation. Site location is in the parish of the village of Dolovo, on the terrain made out of Loess dusty sands and dusty clay sediments.

Gornji Milanovac (K – 4) – The existing municipal waste disposal site "Vujan" is located at around 4 kilometres downriver from the town, and envelops a ravine that was formed in the serpentine massif. Serpentine rock mass that forms the basis of the landfill site's body is intensely cracked and is susceptible to disintegration and break down. Detailed geotechnical and hydro-geological investigations determined the conditions of sanitory improvement works at the site, which are presently being done.

Sjenica (K – 4) – Based on the necessary geotechnical conditions and other criteria, an adequate location has been found in the surrounding area – "Govedjak". The site foundations are formed in the rocks of diabase-flint formation (claystones, loam, flints and loamy limestone). The rock mass is dominated by claystones and loam and is considerably damaged; with broken-down surface and deluvial mass 0,3 - 2,0 metres in thickness. The sites stability is secured by dam construction at the bottom of the ravine, stripping of the deluvial overlay and by a correct order of waste disposal – starting at the dam and moving towards the ravine's forehead.

Užice (K – 4) – To relocate the existing landfill site " Sarica Osoje" a new location has been chosen to the north-east of the town, on a left valley side of Turski stream. Basis of the terrain is composed by a complex of semi-metamorphous deposits of the Drina Palaeozoic (sericitic and sericitic-chlorate shale, argillaceous stones, filites and metamorphous sandstones) covered by a eluvial-deluvial coat, and in the zone of Turski stream by alluvial-proluvial deposits. Because of frequent changes in the thickness of clay debris which represents the basic breakdown of this type of rock, the stability of planned hillsides of the landfill sites present a problem.

Figure 4. Municipal waste disposal ground for the town of Uzice (photo: N.Susic, 2005)

Negotin (K – 3) – Terrain immediately surrounding Negotin is made out of alluvial and river-terrace sediments with Neogaean edges on the west side of the area. Chosen alternative solutions to the location question in the terraced, mainly gravelly surroundings isn't the best solution from the hydro-geological aspect (the village of Korbovo – zone of abandoned gravel pits). Those are the reasons for undertaking solid hydro-insulation works atop permeable basis.

Leskovac (K – 2) – Location north-west of the town has been chosen as a new location of the waste disposal site as a temporary solution. The basis of this site is crystallised slate of Serbian-Macedonian mass (mainly gneiss) which presents a fairly suitable environment for deposing the site body.

Belgrade (Batajnica) (K – 2) – Abandoned open-cast clay mines in loess sediments have been used as municipal waste disposal sites. Geological investigations have been conducted for the purposes of planning the re-cultivation – that is the closing down of the site (investigative boring to build in the piezometers inside the main body of the site as well as around the edges, test-digging for investigating water retention by method of saturation). Monitoring has been established, but further control is not expected.

Novi Pazar (K – 1) – A landfill site is located on the southern side of terrain, in close proximity to the Novi Pazar – Ribarice road zone, and the terrain is built of shale metamorhites (chrystal slate). These rock masses, with appropriate measures, present relatively good foundations for landfill site body with respect to their hydro-geological conditions. Terrain stability presents the biggest problem of this location. Small scale landslide have occurred on the upper degraded zone and deluvial mass, due to the inadequacy of works done,.

Pirot (K – 1) – During the deliberations about the future landfill site location, the southern side of the area has been eliminated as it is made mainly of carbon based rocks (karsts environment) and it presents a large collective surface conributing to the underground waters. This is the reason why the location of "Muntina padina" in the north-easterly part of the area has been suggested, not far from the main road to Belgrade. The ground is made up from the volcanic rocks (agglomerates, breccias and tuffs) that are relatively water-resistant, but landslides are obvious in a deluvial subsurface zone. Activities connected to the finalisation of the design documentation are taking place at present.

Figure 5. Location of the future regional landfill site "Muntina padina" in Pirot (photo: D.Rakic, 2005)

Arandjelovac (K – 1) – Until the end of 1980's, the disposal of the municipal waste has been done on the flood planes of river Kubrsnica, downriver from the town. Geological conditions on that location were very unsatisfactory, and a new location has been chosen – on a Neogene terrain north-west from the town. As part of the planning process, detailed geotechnical and hydro-geological investigations have been made. The new landfill site is under construction, but it is still unfinished.

Figure 6 shows the typical engineer-geological terrain models in the zones of existing, re-cultivated and newly designed landfill sites on the territory of Serbia.

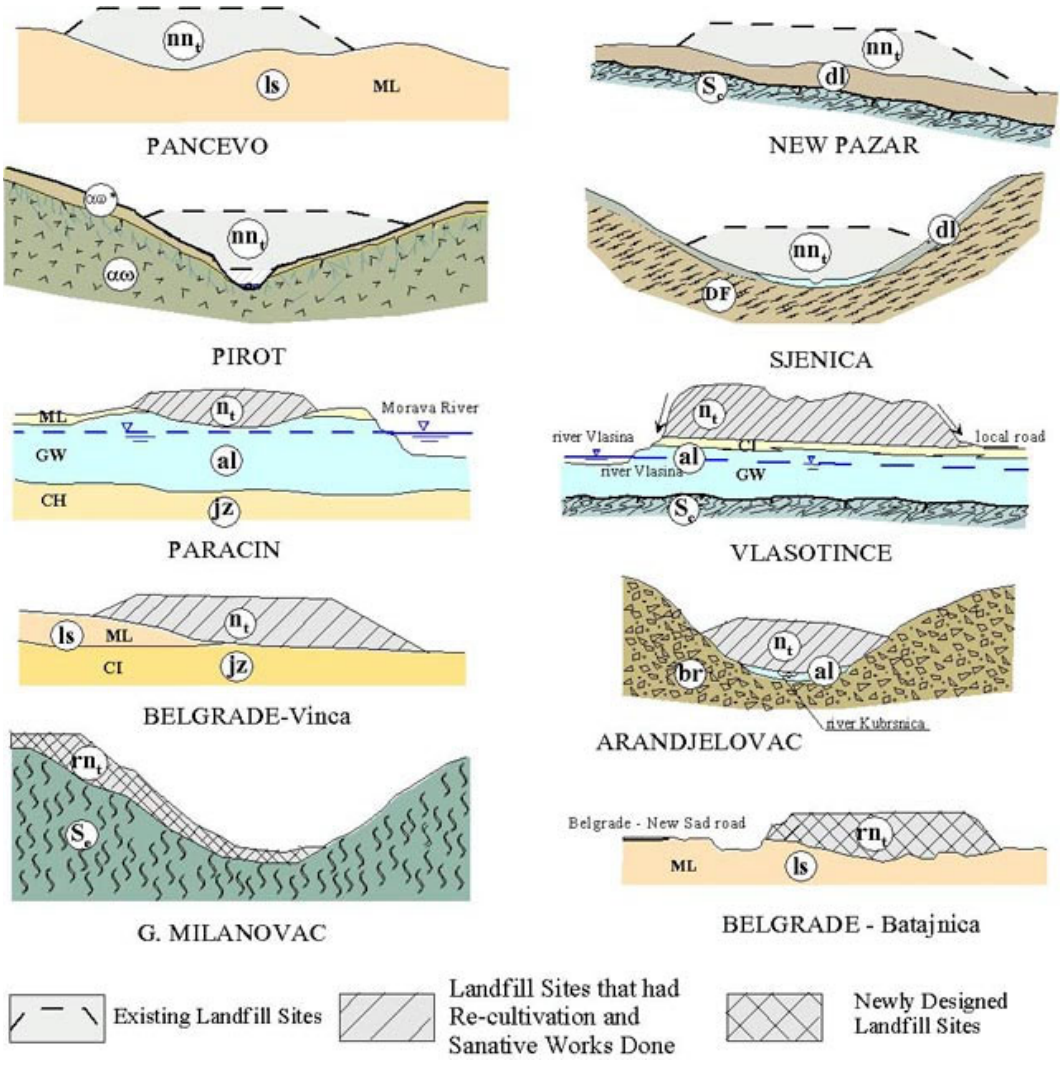


Figure 6.Typical engineer-geological terrain models in the zones of existing, re-cultivated and newly designed landfill sites on the territory of Serbia

CONCLUSION

Waste disposal that is safe is the goal of every society and prerequisite of sustainable development. That is why the landfill sites are located in the zones where their influence on the ground, underground and surface waters can be controlled and minimised. Depending on the type and quantity of waste; geological, geotechnical and hydro-geological soil characteristics and distance of underground and surface waters, different design solutions are produced.

The following problems of a geological nature have influenced or become evident in the construction of new and existing municipal waste disposal sites:

- Impermeability of the landfill site's basis/foundations, typical of planes – alluvial terrains and
- Hillside and slope stability, typical of rolling-hills – Neogene terrains.

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