Environmental and social issues associated with aggregate extraction: The Lafayette - West Lafayette, Indiana, and other examples, USA

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Abstract: In 1995 Purdue University acquired a 500 acre tract, an unreclaimed gravel pit complex located adjacent to the main West Lafayette campus. With an existing campus of about 600 acres, the new acquisition nearly doubled the size of the campus. Begun in 1918 gravel extraction occurred for 80 years. Located on the terrace complex of the Wabash River at Lafayette, gravel pits extend from the Upper or Mississinewa Terrace to the Lower or Maumee Terrace with elevations of 600 to 640 feet and 560 to 570 feet, respectively. The Lower Terrace lies about 50 feet above the Wabash River floodplain. The groundwater table occurs 26 to 300 m below the Upper Terrace. Nearly 50 feet of sand and gravel were mined and layers of blue clay encountered. Extensive construction was accomplished, a materials distribution center, cooling towers for the power plant and a coal storage area. A service road was constructed using coal ash from the fluidized bed, power plant on campus. A construction-demolition landfill was built. This allowed Purdue to move non-academic functions off the main campus. Mapping of near-surface materials to find clay deposits occurred. Cohesive material for pond liners, landfill cover and embankments was required. Borings for gravel extraction and more recent ones for hydrogeologic studies were used to construct post-mining cross sections. Gravel extraction could not extend beyond a county road without a zoning change, but public opposition prevented this. The mining company traded land for mining rights to the last available tract. West Lafayette could not grow westward because of the gravel pit or eastward because of the Wabash River. Gravel extraction adjacent to the Purdue campus illustrates the conflict between aggregate production and urbanization. Opposition to mining increases with population growth and NIMBY ('not in my backyard') sets in. Additional examples from Indiana and Nevada, USA, are cited for comparison. As natural aggregates occur only in specific locations, cooperation and planning are required to minimize conflicts and allow extraction to continue near the point of use. Secondary effects from mining must be minimized.

Résumé: En 1995, l'université de Purdue a acquis un terrain de 500 acres, un complexe de complexe de carrières de graviers abandonnées situé en bordure du campus principal de West Lafayette. Étant donné la surface existante du campus, 600 acres, cette nouvelle acquisition a presque doublé la surface du campus. Commencée en 1918, l'extraction du gravier a eu lieu durant 80 ans. Situées sur un complexe de terrasses de la rivière Wabash à Lafayette, les carrières s'étendent de la terrasse supérieure (ou Mississinewa) à la terrasse inférieure (ou Maumee), à des altitudes de 600 à 640 pieds et 560 à 570 pieds, respectivement. La terrasse inférieure est située à environ 500 pieds au-dessus du lit majeur de la rivière Wabash. L'aquifère de surface se trouve entre 80 et 100 pieds sous la terrasse supérieure. Près de 50 pieds de sables et graviers ont été extraits et des niveaux d'argile bleue ont été rencontrés. D'importantes constructions ont été entreprises, un centre de distribution de matériaux, des tours de refroidissement pour la centrale d'énergie et une zone de stockage de charbon. Une route de service a été construite avec les cendres de charbon de la centrale énergétique du campus. Une déchetterie a été construite. Ceci a permis à Purdue de déménager des fonctions non-académiques hors du campus. Une cartographie des matériaux de surface a été entreprise pour trouver des dépôts d'argile. Des matériaux cohésifs pour les embarcations d'étangs, pour la couverture des déchets et le renforcement des berges a été nécessaire. Des forages utilisés pour l'exploitation des graviers et, plus récemment, pour des études hydrogéologiques ont été réutilisés pour construire des coupes post-exploitation. L'extraction des graviers aurait pu s'étendre au-delà d'une route de comté avec une modification du zonage, mais le public s'y est opposé. La compagnie minière a échangé le terrain contre des droits d'exploitation jusqu'à la dernière parcelle disponible. West Lafayette ne pouvait pas s'étendre vers l'Ouest à cause des carrières de graviers, ni vers l'Est à cause de la rivière Wabash.

Keywords: environmental geology, excavations, gravel, reclamation, aggregate, land use

INTRODUCTION

Reclamation of the abandoned gravel pit complex adjacent to Purdue University, in West Lafayette, Indiana provides an excellent opportunity to consider the potential conflict between aggregate extraction and long-term land use. The economic contribution of aggregates in construction is counter-balanced by the environmental impacts of such use. In 1995 Purdue University acquired a 202 ha tract, an unreclaimed gravel pit complex located adjacent to the main West Lafayette campus. With an existing area of about 240 ha, the new acquisition nearly doubled the size of the university holdings. Begun in 1918, gravel extraction on the adjacent area occurred for more than 80 years. This setting provides an example of land use involving urban sprawl, reclamation and secondary use.

Mineral aggregates have played a major role in advancing engineering construction projects for the last 100 years. Improved concrete construction provided a steady advance in economic progress. In fact, human progress closely parallels advances in construction methods and more efficient utilization of building materials. However, this progress has not come without environmental consequence. Pits and quarries remain open long after extraction of mineral aggregates has ceased. In some cases, groundwater levels were lowered by pumping to enhance mining operations. Secondary effects, such as surface settlement and underground collapse occur as a consequence. Both environmental and economic complications may develop due to the extraction of construction materials (Mason & Welgoss 2002).

Utilization of mineral aggregates is basic to the production of Portland cement concrete. Aggregates consist of sand, gravel, crushed stone, blast furnace slag and other materials used with binders to form bituminous and Portland cement concrete, macadam, mortar and plaster, or alone as railroad ballast, filter beds, fluxing materials and scrubber materials for coal-fired power plants (Woods 1960). Aggregates are necessary ingredients for highway pavements and structural concrete, accounting for 30% of the cost, and comprising by volume 65 to 85% of concrete and 92 to 96% of asphalt pavements. Natural aggregates consist of rocks and minerals, but blast furnace slag and expanded clay or shale (lightweight aggregates) are also utilized.

Geologic challenges must be overcome during exploration for and exploitation of mineral aggregates. Geologic factors and physical restraints play important roles affecting the economics of extraction. Today the aggregate production industry faces serious challenges, as the general public seems oblivious of the impact that mineral aggregates have on construction costs in urban areas. By contrast, aggregate companies must be sensitive to environmental concerns and the potential for detrimental effects on the environment. Aggregate mining results in pits, surface quarries and underground mines, which should be reclaimed or stabilized after mining. Today, reclamation plans, typically must be approved before aggregate extraction can begin (Barksdale 1991). Quarry/pit/underground mine operators must learn to cooperate with the general public so as to minimize the negative effects of the extraction process. The short-term problems associated with extraction could evolve into long-term benefits by establishing lakes, parks and other public facilities on mined out sites. Hopefully, residents will adopt a more reasoned approach in acceptance of the mineral extraction industry and its beneficial contribution to the local economy.

AGGREGATE DEPOSITS

Logic dictates that aggregate materials must be present at a specific location before extraction can proceed. This seems obvious, yet is not fully appreciated or accepted by the general public. Gravel supplies, for example, occur in only certain specific locations in the terrain and under special geologic conditions. Aggregate supplies have a high "Place Value" where a close location to the point of use is economically important (Flawn 1970). The discussion below focuses on the occurrence of these natural materials.

Sand and Gravel Deposits

Several factors influence the location of commercial sand and gravel operations. These include: quantity of the deposit (volume), quality of the gravel, thickness of overburden, location of the groundwater table and drainage conditions for the site. Exploration and a subsequent testing program should determine these details (West 1995). Test borings are used to determine the volume of the deposit. The number of borings ranges upward from a minimum of three per site for preliminary studies. This is increased to one boring per 2 ha for estimated reserves to one boring per 0.4 ha for proven reserves. Grain size analysis and quality evaluation comprise the laboratory tests. The amount of gravel versus sand in a deposit is an important factor for most operations. A minimum of 25% gravel is typically required for an economically, feasible development. Typically, tests include the Los Angeles Abrasion loss, freeze thaw loss, absorption/specific gravity and an analysis of deleterious materials, performed to determine the quality and variability of a source.

Rhoades (1950) presented an outline of the sources for sand and gravel, referring to them as natural aggregates. He pointed out that alluvial and glacial fluvial environments were most productive in this regard and then provided a list of geologic environments in which gravel deposits are present. These include alluvial deposits (stream channels and terraces, flood plains and alluvial fans), glacial-fluvial deposits (outwash plains, valley train deposits, kames and eskers and portions of end moraine complexes), gravity controlled deposits (talus slopes and scree material), coastal plain deposits (beach sands and marine terraces) and residual deposits (weathered bedrock and disaggregated mineral deposits).

Alluvial deposits are prevalent in many urban areas as most cities were founded along major river courses. However, urban growth has covered many alluvial deposits, effectively excluding them from the extraction process. In glaciated areas of the Midwestern U.S., sand and gravel deposits are abundant in valley trains, outwash plains and alluvial deposits. Unfortunately, these locations have succumbed to urban sprawl in many populated areas, requiring the need to transport gravel over longer and longer distances to their point of use. In some cases where extraction has occurred, post reclamation efforts have been inadequate. Today, with zoning requirements in place, site improvement after mining is becoming a common practice.

To encourage the utilization of sand and gravel deposits near urban areas, the existence and location of these materials must be established in advance of urban sprawl. Geologic mapping of surficial materials is an important step in the preservation process. This has been accomplished for most major cities in the United States as both state geological surveys and the U.S. Geological Survey recognized the importance of this activity some years ago. In Indiana, geological reports on the state's major cities were prepared several decades ago by the Indiana Geological Survey (Hartke *et al*. 1980). For smaller communities such detailed geologic reports are lacking.

THE LAFAYETTE-WEST LAFAYETTE, INDIANA EXAMPLE

The Lafayette-West Lafayette urban area, home of Purdue University, is located in Tippecanoe County of northwest Indiana. Tippecanoe County has a population of about 150,000. Purdue University is a state supported university with an enrollment of approximately 38,000 students. It is a major university located in the mid-portion of the U.S. A tier one research institution, it is part of the Big Ten Conference of universities. Surficial maps for the County providing some geologic detail are available in the published literature. The Engineering Soils Map of Tippecanoe County (Yeh 1963) supplies details on surficial materials at the scale of 1:63,360. This map, developed from aerial photography, provides information on landforms and on engineering soil properties. The USDA Soil Survey of Tippecanoe County (1998) yields details on the agricultural soil series in the form of base maps at 1:15,840 scale. These soils, developed on Wisconsin-aged glacial materials, present information that can be used to discern the location of sand and gravel materials.

Sand and gravel deposits in Tippecanoe County are associated primarily with the Wabash River system and its major tributaries, Wildcat Creek and Wea Creek and the Wea outwash plain. Terrace deposits are prevalent along the Wabash River in the Lafayette-West Lafayette area. Purdue University is located on an extensive terrace on the west side of the river.

The Vulcan Materials gravel pit site illustrates the concept of good cooperation between an aggregate producer and its neighbor. Sand and gravel were extracted from the Purdue terrace for over 80 years beginning in 1918 (Pittenger *et al*. 1995, West *et al*. 1995). The groundwater table lies between 26 and 30 m below the ground surface so that the 9 to 15m deep excavations were accomplished under dry conditions. Below this depth the deposit consists mostly of sand so that economic mining of gravel was not feasible. Some years ago a small portion of the extensive gravel pit was used as an unlined, sanitary landfill. It was isolated but not retrofitted.

Located on the terrace complex of the Wabash River at Lafayette, gravel pits extend from the Upper or Mississinewa Terrace to the Lower or Maumee Terrace with elevations of 183 to 195 m and 171 to 174 m, respectively. The Lower Terrace lies about 16 m above the Wabash River floodplain. The groundwater table occurs 26 to 30 m below the Upper Terrace. Nearly 15 m of sand and gravel were mined but layers of blue clay (glacial till) were encountered during excavation.

On the area acquired from the gravel company, extensive construction was accomplished by the university. This included a materials distribution center, cooling towers for the campus power plant and a coal storage area. A service road was constructed using coal ash from the fluidized bed of the campus power plant. A construction-demolition landfill was built (Tischmack 2000), which receives construction debris from university construction projects. Acquisition of the 202 ha tract comprising the former gravel pit allowed Purdue to move non-academic functions off the main campus.

Mapping of near-surface materials was employed to find clay deposits within the sandy deposits. Cohesive material for pond liners, landfill cover and embankments was required. Borings for gravel extraction and more recent ones for hydrogeologic studies were used to construct post-mining cross sections.

Gravel extraction could not extend beyond a county road without a zoning change, but public opposition prevented this from occurring. The mining company traded land for mining rights to the last available tract. Mining in the area ceased when this last area was excavated in 1998.

A negative effect of the extensive area of the abandoned gravel pits was its restriction to urban development. The combination of land owned by Purdue University (202 ha) and the 240 ha of gravel pits prevented West Lafayette from expanding to the south. Since the city could not expand eastward because of the Wabash River, further urbanization was limited to growth in the northern and western directions. The gravel extraction operation could have continued to the south, if a conveyor system was extended over an existing county road. Local residents resisted these zoning changes, so the mining process ended. Gravel extraction is now conducted north of Lafayette-West Lafayette along the Wabash River on a low-lying terrace deposit. Another location for gravel extraction is along Wildcat Creek on the eastern edge of Lafayette. An additional area of sand and gravel deposits occurs on Wea Creek outwash plain just southeast of the Wabash River.

ENVIRONMENTAL IMPACT OF THE AGGREGATE EXTRACTION PROCESS

Extraction of sand and gravel from surface deposits creates depressions in the Earth's surface. In the past, these depressions were utilized to dispose of solid and industrial wastes, and thereby re-establish the former land surface. Current regulations prevent the placement of solid waste in unlined pits and quarries, but much damage was inflicted before these regulations were established. Groundwater contamination within industrial areas is one result of this practice. Recent landfill closures under Indiana state law and Federal Superfund regulations have mitigated some problems, but many, contaminated sites await cleanup action. Aggregate mining can also inflict a significant nuisance effect on the neighboring community. Environmental problems from mining can be manifested as air, water and noise pollution (Mason & Welgoss 2002). In addition, groundwater drawdown and penetration of contaminants into aquifer systems are possible consequences. Drainage problems from industrial plant operations are another concern.

An example of this situation is a groundwater contamination problem at the Gary Development Landfill, Gary, Indiana. It is located immediately north of the Indiana Toll Road near the northwest corner of Indiana, and adjacent to the Little Calumet River in Lake County (West 1988). The landfill lies about 20 miles east of Chicago, Illinois. Gravel was excavated from the site and used as road base for highway construction in the early 1900s. Following removal of gravel, the pit became filled with water. Subsequently the pit was dewatered and a compacted clay liner was placed on the sides and bottom. It was operated as a sanitary landfill until it closed when stricter landfill requirements were enacted by the Indiana Department of Environmental Management. Groundwater contamination in this industrial area of northwest, Indiana is extensive. Although steel mills and oil refineries are also present in the area, abandoned landfills have contributed to this groundwater contamination.

Lowering the groundwater table in cohesionless soils causes settlement of the ground surface. Compaction of the granular structure occurs as the effective stress is increased when pore pressures are reduced. This is a common problem in all construction sites where dewatering of permeable soils is conducted. To prevent such subsidence the groundwater must be recharged into the aquifer some distance away from the pumping site. This phenomenon known as shallow subsidence has occurred along the White River floodplain of Indianapolis where several sand and gravel pits have operated for many years (Sudar 1987, West & Warder 1983).

Examples exist where extensive lowering of the groundwater table during gravel pit mining caused the migration of contaminants from near by facilities toward the opening. The Sparks Marina project near Reno, Nevada, USA is such an example (AEG News 2002). Contamination from a petroleum tank farm at a pipeline terminal yielded a major off-site contamination problem. Cleaned up under a US-EPA order, the pit formed by gravel extraction was subsequently developed into a marina area for small boats, with a beach and amusement park provided for the general public. The contaminated plume from the tank farm is being mitigated by vapor extraction and biodegradation. An acceptable water level in the marina is maintained by pumping water into the nearby Truckee River. This impacts their NPDES permit, and existing limits require that nitrogen levels be reduced before discharging water into the river.

OVERVIEW OF AGGREGATE EXTRACTION AND ENVIRONMENTAL EFFECTS

Aggregate production from sand and gravel pits contributes significantly to the U.S. economy. New construction and upkeep of infrastructure require that aggregates be available at an economically acceptable cost. However, environmental concerns and effects on neighboring property are significant. Human activities to obtain aggregate materials contribute significantly to the impact on the Earth's environment and pose a concern for the future. Cooperation between aggregate producers and property owners can minimize environmental conflicts.

The precept of NIMBY - Not In My Back Yard - is prevalent. Contrary to assumptions expressed by some citizens, sand and gravel production can be accomplished only in specific geologic locations. Better planning and zoning ordinances could alleviate or minimize some shortage problems.

In most cases, aggregate producing operations predate the construction of homes in an area. Continued operation, not a newly located production site, is the common issue. In some cases, lateral expansion of the production site has been requested. Aggregate producers, however, need to adjust to the concerns of their neighbors, whereas homeowners should appreciate the need for aggregate supplies near the point of construction. True cooperation is required between these two entities to reduce environmental effects while allowing mineral extraction to continue.

Secondary use of pits and quarries can provide a positive contribution. If these abandoned excavations fill with water they provide a setting where attractive home sites and recreational areas are developed. Along the White River in northeastern Indianapolis, Indiana, USA, expensive homes have been constructed along water-filled, abandoned gravel pits. However, in West Lafayette, south of the Purdue University campus, gravel pits remained dry when abandoned. Because the groundwater table was well below the land surface in this terrace deposit, the sandy deposits could not support a body of water. This extensive zone of dry excavations actually acted as a deterrent to systematic growth of the city to the south. Only recently has the land been used in a functional way through the expansion of the Purdue University campus.

The preceding discussion on the gravel/sand industry shows the profound effect on the environment. Human activities under these conditions illustrate the complex relationship between humans and their dependence on raw materials production and other industrial activities. Alluvial areas, the sites for sand and gravel production, are particularly sensitive areas regarding ground- water supplies and possible contamination. These landforms possess a high hydraulic conductivity and saturated conditions and mark the typical sites where cities were first established. Urbanization can lead to groundwater contamination and the loss of available mineral resources.

Cooperation and planning are needed to minimize the negative effects, and thereby allow mineral extraction to continue. Environmental impact from mining of construction aggregates has yielded a significant effect on nature, a major example of human influence on the environment. The aggregate extraction process illustrates how humans affect the environment and shows the need to modify past practices in order to minimize environmental impacts.

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