

THE USE OF NATURAL RESOURCES FOR SUSTAINABLE ROADS

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1 INTRODUCTION

The concept of sustainable roads has, until recently, had the connotation of assessing whether the road can be effectively operated and maintained over its design life. Sustainability in this context is thus related to the economics of ensuring that the road remains a cost-effective, operational and valuable asset.

In terms of “sustainability science”, sustainable roads introduce a new concept related to the minimisation of the use of natural resources during the construction, operation, maintenance and rehabilitation of the road network. Road construction is, by its nature, a highly resource intensive and material dependent industry that utilizes large quantities of construction materials, water and energy. Careful consideration of the sustainability issues should become essential components of every road design project.

In road provision, sustainability issues primarily include virgin material and water conservation although energy can be considered as an “indirect” natural resource utilised in road construction. This chapter reviews the relevant sustainability background and identifies areas that should be considered in relation to conserving non-renewable natural resources. Techniques that can contribute to reducing the use of non-renewable resources are introduced.

2 BACKGROUND AND FUNDAMENTAL CONCEPTS

The inclusion of environmental impacts in road project evaluations first started in a small way in the 1970’s but became an essential component of most projects worldwide only in the late 1980’s (and in South Africa in the early 1990s (Paige-Green et al, 1991)) following the Report of the World Commission on Environment and Development (Brundtland Commission) in 1987 and the declaration at the “Rio de Janeiro Earth Summit” (UN Agenda 21) in 1992 with implementation of Agenda 21 being reaffirmed at the Johannesburg World Summit on Sustainable Development in 2002.

The early Environmental Impact Assessment (EIA) process was primarily related to negating pollution (of soil and groundwater), aesthetic disfiguration and ecological impacts. Modern EIA’s are integral parts of any project and cover a considerably wider range of impacts such as ecological and aesthetic degradation, social and cultural impacts and pollution, again with little attention being paid to the consumption of natural resources.

Sustainable development was defined by the Brundtland Commission as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Specific reference was made to the over-exploitation of non-renewable resources (particularly fossil fuels and minerals) where it is stated that “the resource should not run out before acceptable substitutes are available”. This is specifically applicable to fuels and industrial minerals, but does not really highlight construction materials or water, which are unlikely to ever be replaced by a substitute.

In the context of this paper, United Nations Agenda 21 makes wider reference to natural resources including “soils, minerals (geological) and water” although there has been little reported in this direction locally.

Conventional sustainability science is primarily related to “socio-ecological science” (du Plessis, 2008) which by implication concentrates on the relationship between humans and living organisms, although there is occasional reference to sustainable use of minerals.

The move to increasing the “greenness” of roads has recently led to various techniques for assessing the sustainability of projects. The Green Roads rating system (Soderlund et al, 2008) was developed for road design and construction and was based loosely on the LEED system (Leadership in Energy and Environmental Design, 2009). It is, however, considerably simpler to use and originally consisted of credits in 6 categories within which up to 54 credits could be obtained. This included a category for “Materials and Resources” that awarded credits directly for aspects such as the minimization of construction waste, recycling of existing materials and minimization of transportation impacts. In all a maximum of 11 credits could be achieved in the category if all aspects of sustainability referred to were optimized. As this was developed in the rather moist state of Washington, USA, little consideration was directed towards minimizing the use of construction water.

Green Roads has since been updated (Muench et al, 2009) and now consists of 7 categories in which 62 possible credits can be obtained. The category “Materials and Resources” has changed somewhat and now includes 12 credits out of the total 62.

3 NON-RENEWABLE RESOURCES

The most important non-renewable resources discussed in this chapter include rock and its weathered derivatives (gravel and soil) and water although energy use in construction is briefly highlighted.

3.1 Rock and soil

An inspection of any geological map of South Africa will indicate that the land area consists of many hundreds of different geological formations. Each of these has a characteristic upper portion depending on the climate and topography, with the geological formations being overlain by various thicknesses of residual weathering products or transported materials, from almost non-existent to tens of metres thick. It is thus difficult to conceive that materials for road construction are finite. However, not all materials are suitable for road construction purposes and, in fact, the majority of surface materials are considered unsuitable.

Materials for road construction purposes are required to conform to a range of physical and chemical properties that severely limit the availability of gravel materials (primarily weathered and transported rock). Materials for stronger pavement layers, surfacing and concrete are generally derived from the crushing of rock and, although expensive and environmentally unsatisfactory, many rock types can be used as sources.

Sustainability issues related to construction materials mostly revolve around minimizing the use of soil and rock resources that are either limited locally or could be more beneficially used for other construction purposes at a later stage (Paige-Green, 2009). Unlike the mining of commercial minerals that are generally of limited extent and are mined to fulfil specific human needs, soils and rock are considered to be ubiquitous. Experience has shown, however, that the injudicious use of certain selected construction materials (particularly pedocretes) has led to their depletion and materials of a lesser quality now need to be utilized in their place. In the case of unsealed roads, this has led to poorer performance and higher road user costs as well as aspects such as increased dustiness, erosion and gravel replacement.

The use of natural gravels as wearing courses for unsealed roads are a particular case in point. An 8 m wide unsealed road typically requires about 1200 m³ of selected wearing course gravel (compacted in a 150 mm thick layer) with specific properties. The gravel surface on such a road carrying about 200 vehicles per day would normally last about 6 or 7 years before it is lost by abrasion, whip-off, erosion (water and/or wind) and requires replacement. The material that is lost ends up as dust on vehicles, vegetation and in rivers, as eroded material in water courses and as non-reusable segregated material along the edge of the road.

A more sustainable option would thus be to provide a bituminous seal which would preserve the same quantity of material for a period of at least 20 years after which time it can normally be reused as a new structural layer in the rehabilitated road.

Even for paved roads, a number of sustainability alternatives exist. The prize option would be to use existing waste materials such as mine wastes that are present locally. These are often widely available and although they may have specific problems (e.g. high sulphide or salt contents), these can usually be overcome using appropriate construction techniques.

The use of thinner pavement layers constructed of higher quality materials instead of thick lower quality layers can also have sustainability benefits. The identification of locally available marginal quality materials that can be treated with cementitious or bituminous stabilizers should also be considered.

For lightly trafficked roads, the use of bituminous sand seals constructed using suitable sands extracted from large, mostly intermittent, rivers is always a more sustainable option than using seals that require crushed stone. Such sands are replenished each year during flooding of the river (they are thus arguably considered as renewable resources) and can often be successfully used instead of conventional aggregates that require mining, crushing and sieving.

A common problem observed is the construction of excessively wide road pavements. Where materials are scarce, a possible reduction in the road width should be considered – a 7 m wide road would reduce the material requirements by more than 20 per cent, for instance over a more conventional 9 m wide road.

In areas with limited high quality road construction gravels, consideration should be given to designing highways such that they can be effectively maintained without requiring significant additional materials over a 40 or 50 year period (perpetual pavements (Steyn and Paige-Green, 2009)) instead of the current practice of designing the road to “fail” and be either reconstructed or require significant rehabilitation every 15 or 20 years. Harder and more durable materials that are more likely to be successfully recycled in future (e.g. quartzitic gravels) should be proposed for use rather than those materials that are likely to be subjected to decomposition (e.g. basic crystalline rocks) or disintegration (e.g. sandstones and gneisses) in service.

3.2 Water

The majority of South Africa can be considered to be water deficient, with 85 per cent of the country having a water demand (loss by evapotranspiration) exceeding the water supply (by precipitation). This is illustrated by the work of Thornthwaite (1948) and a subsequent revision of his map (Leyland and Paige-Green, 2009) where Thornthwaite’s Moisture Index values of less than zero are indicative of water deficient areas with deep water tables. This also applies to the majority of southern hemisphere countries as well as many countries in the northern hemisphere, particularly the Middle East, India and parts of China. Ongoing extraction of groundwater in arid areas, thus results in an overall depression of the groundwater table.

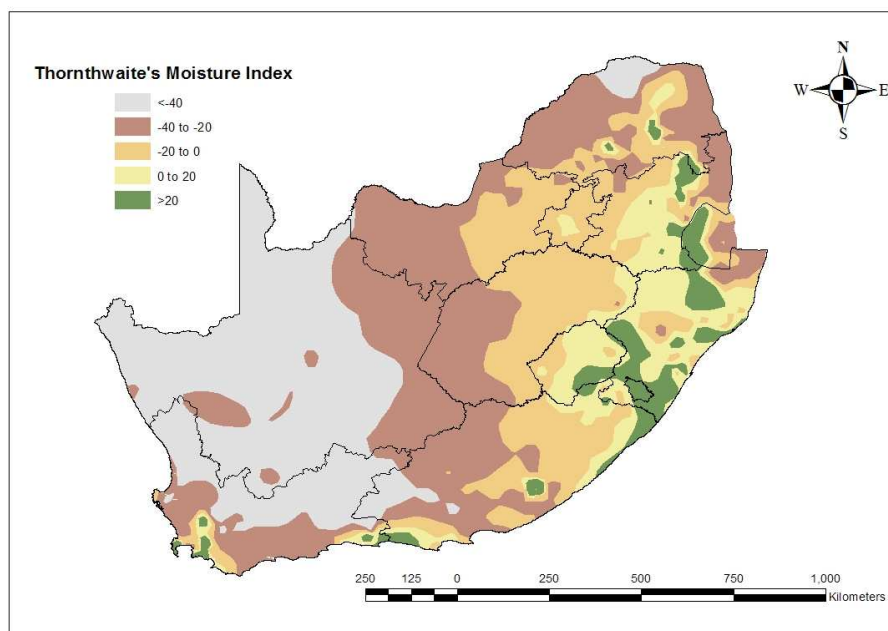


Figure 1: Thornthwaite’s moisture index for South Africa

Research and experience have shown that alternative methodologies can be used to reduce the impact of road construction on water resources. Although many of these techniques still require research and refinement it is important that they be considered as alternatives to conventional practice. Details concerning these are discussed by Leyland and Paige-Green (2009).

3.2.1 Reducing compaction water

Traditional material compaction processes used in the construction of roads, railways and pipelines require that the moisture content of the material is raised to the “optimum moisture content” (OMC) of that material at which point the shear strength created by soil suction at low moisture contents is minimised and the rearrangement of soil particles during the essential process of compaction requires less energy to achieve. In broad terms, this typically requires the use of about 200 l of water per cubic metre of material (or between 150 and 200 thousand litres of water per pavement layer per kilometre of conventional road pavement). The amount of water required to reach OMC is increased in arid areas where the natural moisture content of the soil is low and high temperatures result in a significant loss of water by evaporation during the construction process. Thus in arid areas the cost of supplying water for construction projects has been known to comprise up to 25% of the total construction cost.

Research into the compaction of material without the addition of water is, however, not a new development with research by Ellis (1980) and O’Connell (1997) showing the potential feasibility of low moisture content compaction. The results are, however, very material and equipment dependent and tests should be conducted to

determine the feasibility of this for different materials. Dry compaction should always be considered in dry areas. Construction during the rainy season can also benefit from the moisture content of local materials being raised by the rainfall, which will result in less water being required to be added during construction.

Low moisture content compaction is thus a viable option but the effects of moisture changes in the road layers after construction still require further research, especially for finer grained soils. The fact that the methods may be restricted to fill, subgrade and selected layers is acceptable as these materials make up the largest volume of construction materials and therefore will result in the largest savings in water (and also costs). Laboratory compaction methods have been shown to not accurately and consistently predict field density as the compaction methods used are generally designed for a specific soil state (O'Connell, 1997) and the compaction efforts used do not necessarily represent those applied by modern construction equipment. It is essential that realistic relationships between density, moisture content and compaction effort are derived for each new material before dry compaction is attempted on a major project and that the laboratory results are confirmed during full-scale field trial sections.

The use of commercial surfactants as compaction aids assists with lubrication of the soil particles in certain materials during compaction and can reduce the moisture content required for compaction by 2 or 3 per cent. This can be a cost-effective technique for saving water on large projects in arid areas.

Success with dry compaction has also been achieved with the use of High Energy Impact Compaction (HEIC) in Botswana and elsewhere (Pinard and Ookeditse, 1988). This technique makes use of heavy non-circular "rollers" (square or triangular) that impart energy to the layer being compacted by the "rollers" falling from their corners or apices. The impact energy results in the ability to achieve high densities in many materials at the natural moisture content of the soils.

Recent trials during the construction of unsealed road experiments in the Mpumalanga Lowveld during summer have clearly shown the benefits of using recycling machines. Conventional construction using motor graders for mixing the water into the material could not keep up with the evaporation resulting in the ongoing addition of water to the material during mixing and compaction. A second set of trial sections using a modern in situ recycling machine for the addition of water and mixing allowed the exact amount of water to be added to the material (adjusted as necessary on site) and compaction immediately behind the machine. No additional water was required during the process and significantly less water was utilised.

3.2.2 Other construction water requirements

Apart from compaction, water is also required for various other activities from washing construction equipment to curing chemically stabilized layers and concrete. The curing of stabilized layers is particularly wasteful of water and alternative techniques should be carefully assessed to minimise water usage.

In order for the cementation reactions in materials treated with lime or cement to progress fully, water is necessary. The reactions are essentially hydration of aluminium and calcium silicates to produce the standard cementation products, hydrated alumina and calcium silicates. The standard specifications (COLTO, 1998) state that stabilized layers shall be kept *continuously moist* for 24 hours, after which one of 4 different techniques should be employed for at least 7 days. In the interest of simplicity and reducing costs, it is commonly found that stabilized layers are sprayed with water twice a day to assist curing. In most cases, this is insufficient to prevent the stabilized layer drying out between water sprays with detrimental effects on the stabilized layer. It is thus essential to ensure that the most effective curing technique is selected such that the use of water is minimised. This is usually best achieved by covering the stabilized layer with the next (or a sacrificial) layer of material.

Water is often used in agricultural, mining and even residential areas to suppress dust from gravel roads. This requires the spraying of a large quantity of water a number of times a day (and even at night in arid areas). This technique is a blatant waste of valuable water and a number of chemicals (e.g., hygroscopic salts and ligno-sulphonates) have been shown to be very effective dust palliatives. Their use, instead of continual water spraying should always be considered.

Many of the techniques discussed above have been noted informally and not quantified adequately for full cost-benefit analysis purposes. Additional research in many of these areas is still necessary, although much of this could be carried out on ongoing projects without significant cost or interruption of the projects.

3.2.3 Low quality waters (high salt contents)

Water used in construction generally needs to be of near potable quality to avoid possible soluble salt and other problems and is therefore usually extracted from suitable groundwater resources in drier areas. It is difficult to justify the use of such large quantities of water in relatively arid areas, especially when local communities often struggle to obtain sufficient water even for survival.

When water containing high levels of very soluble salts is available, its use can be considered if appropriate measures are taken to control possible damage caused by salt crystallisation (Netterberg 1979, Roads Department, 2001). The typical problems related to saline waters that have occurred in South Africa are related to evaporation of the compaction moisture at the surface of recently compacted materials with the accompanying precipitation of the highly soluble salts. This results in loosening and weakening of the upper layers of the compacted material affecting the adhesion of bituminous surfacings to the loose material and the associated structural problems in the road pavement.

The problem can be overcome by applying a bituminous surfacing (or a temporary seal) as soon as possible after compaction. In addition, to ensure the long-term avoidance of salt damage, it is essential that the seal is impermeable to water vapour and is not susceptible to cracking. The permeation of any water vapour through the seal will result in the deposition of soluble salts moved through the road beneath the surfacing and the formation of blisters, loosening of the upper layer and loss of the seal. Even when the seal is perfectly impermeable, water will usually escape from beneath the surfacing at the edge of the road resulting in deposition of salts in this area and disintegration (edge break) of the bituminous surfacing along the edge of the road. If carried out timeously, this damage can be repaired and controlled.

3.3 Energy

The energy utilized for construction purposes generally releases large quantities of “greenhouse gases”, considered to be highly unsustainable in the short to medium term. Construction operations that use less energy thus have significant sustainability benefits. By using materials with high “embodied energies” such as industrial waste materials, mine wastes, building demolition rubble, significant energy savings can be made. Essentially these materials are already pre-processed and the energy required to prepare them for construction is significantly less than the energy required to produce a similar quantity and quality of material from virgin rock.

Heating and maintaining high temperatures of bitumen results in high energy consumptions. The use of warm asphalts and bitumen emulsions to improve locally available materials that can substitute for thick layers of asphalt can have significant energy saving and emission benefits and this possibility should always be assessed.

The location of materials for construction must also be considered. Materials that require minimal transportation to the construction site should always be identified and recommended for use.

The energy cost of providing (abstracting, transporting and mixing) potable water in rural areas must be considered. The embodied energy of the final product should thus guide the decision regarding optimal construction methods. It would also be a location-specific alternative, as in areas with abundant potable groundwater, it may be more suitable (cost and energy-wise) for conventional wet compaction.

4 CONCLUSIONS

Road construction uses large volumes of non-renewable materials and water. This is not sustainable in the long term and some mechanisms for reducing this have been identified and discussed. It is important, however, to identify these issues early in new projects and to ensure that all investigations and designs take the optimum solutions into consideration. Many of these may increase the construction cost, but this should be considered in relation to the sustainability benefits that will ultimately accrue.

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