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Concrete Pavement Recycling Series

PROTECTING WATER QUALITY THROUGH PLANNING AND DESIGN CONSIDERATIONS

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Introduction

Use of recycled materials is an inherently sustainable practice, and there are numerous benefits to recycling concrete in infrastructure projects. When using recycled concrete aggregate (RCA), some water quality issues can, on an infrequent basis, occur during both the construction and use phases.

However, water quality concerns associated with concrete recycling have been consistently shown to be mitigated through planning and design considerations, use of conventional best management practices (BMPs), and through readily implementable construction controls.

A summary of the *potential* water quality impacts of concrete recycling, along with a summary of mitigation strategies that can be addressed during project planning and design, is presented in this technical brief.

A summary of *potential* environmental impacts of concrete recycling, including those associated with water quality, air quality, local effects, and waste generation, that can occur during *construction* of a project are presented in a separate technical brief along with mitigation strategies (Cavalline 2018).

Characteristics of RCA Leachate and Runoff

As reported by Steffes (1999) and Sadecki et al. (1996), RCA stockpile runoff and drainage (leachate) from RCA in situ can or may:

- Be highly alkaline (i.e., high pH due to dissolved calcium hydroxide)
- Contain chemical contaminants
- Potentially cause formation of deposits of suspended solids or precipitates in drainage systems or other downstream features

Compared to the total volume of surface water runoff from a project site, the volume of runoff from areas containing RCA (e.g., in stockpiles or drained pavement layers) is typically low. However, runoff from RCA materials can have characteristics that impact water quality near stockpiles and drain outlets, and strategies for mitigating these localized impacts should be considered during both the design and construction phases.

High-pH leachate results from primarily dissolution of exposed calcium hydroxide, a by-product of the hydration of cement. The typical range of alkaline pH from RCA runoff or leachate is shown in Figure 1, along with the normal range of stream pH.

This high-pH leachate can negatively impact receiving natural waters, vegetation, and zinc-coated and aluminum pipe (through corrosion), until diluted with rainfall and other surface waters. Typically, these concerns are restricted to small areas surrounding the drainage outlet, since adequate dilution typically takes place within several feet of the point of discharge (ACPA 2008a).

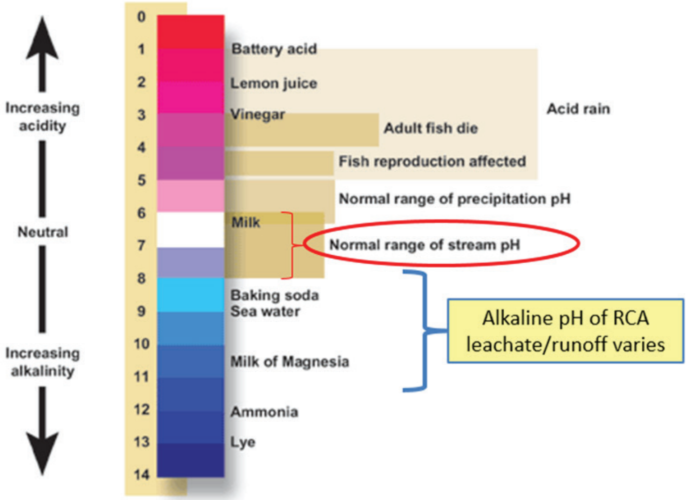
The high-pH runoff is also often neutralized by infiltration and exposure to soils and rock. Placing drains away from receiving waters, along with use of conventional stormwater BMPs, such as bioswales (discussed subsequently in this technical brief), have been shown to mitigate issues with high pH.

RCA leachate and runoff also typically include small amounts of pollutant materials, including “heavy” metals such as vanadium, chromium, and lead (Sadecki et al. 1996, Chen et al. 2012, Edil et al. 2012). **Although these pollutants can occasionally be present in quantities higher than permissible limits for drinking water, dilution of the runoff/leachate and capture or uptake into environmental systems (i.e., bioswales) have been consistently shown to mitigate their impact on receiving waters, particularly when separation is adequate and/or BMPs are used.**

Although drinking water standards are often referenced in research studies related to RCA leachate and runoff, these pollutant limits do not directly apply to runoff and leachate, which do not need to comply with these regulations. Other appropriate criteria (such as those for stormwater quality or permitted discharge to receiving waters) should be utilized in evaluation of RCA leachate/runoff.

Use of RCA in bound applications (such as new RCA concrete or in cement-stabilized bases) significantly decreases the potential for water quality issues associated with leaching, and water quality issues associated with the use of RCA in bound applications have not been reported. Use of fly ash in concrete tends to increase binding of some ionic constituents, further eliminating concerns with potential contaminants in leachate from these applications (Sani et al. 2005).

The potential for deposit formation, which can clog pavement drainage systems, is the result of materials that are dissolved or suspended in the leachate. These deposits are often referred to as calcareous tufa (i.e., calcium carbonate precipitate formed by the reaction of dissolved calcium hydroxide with atmospheric carbon dioxide) and insoluble residue or crusher dust. Several proven strategies to mitigate these concerns are discussed later in this technical brief.



Annotations added to illustration from Environment Canada 2013

Figure 1. Scale indicating typical pH range of RCA leachate/runoff and some common liquids

Deicing salts leaching from RCA could, in theory, adversely change soil characteristics, negatively impact water quality, and damage roadside vegetation (Fay et al. 2013), although this phenomenon was not identified in the literature.

Planning Considerations and Design Techniques that Protect Water Quality

If considered during project planning and design, use-phase water quality concerns can be mitigated or prevented entirely. In fact, **most projects utilizing RCA have been in service for years with no reported water quality or drainage issues** (Cackler 2018). Table 1 provides a summary of the potential water quality concerns for concrete recycling projects, the associated RCA uses, and mitigation strategies considered during project planning and design that have been successfully utilized to address these concerns.

A discussion of each of these concerns and mitigation strategies is presented below. Also, it should be noted that placing the RCA in fill, undrained bases, or other protected layers (including cement- and asphalt-treated base layers) generally limits or prevents removal and transport of crusher dust, calcium hydroxide, and other potential pollutant materials.

Qualification of Source Concrete

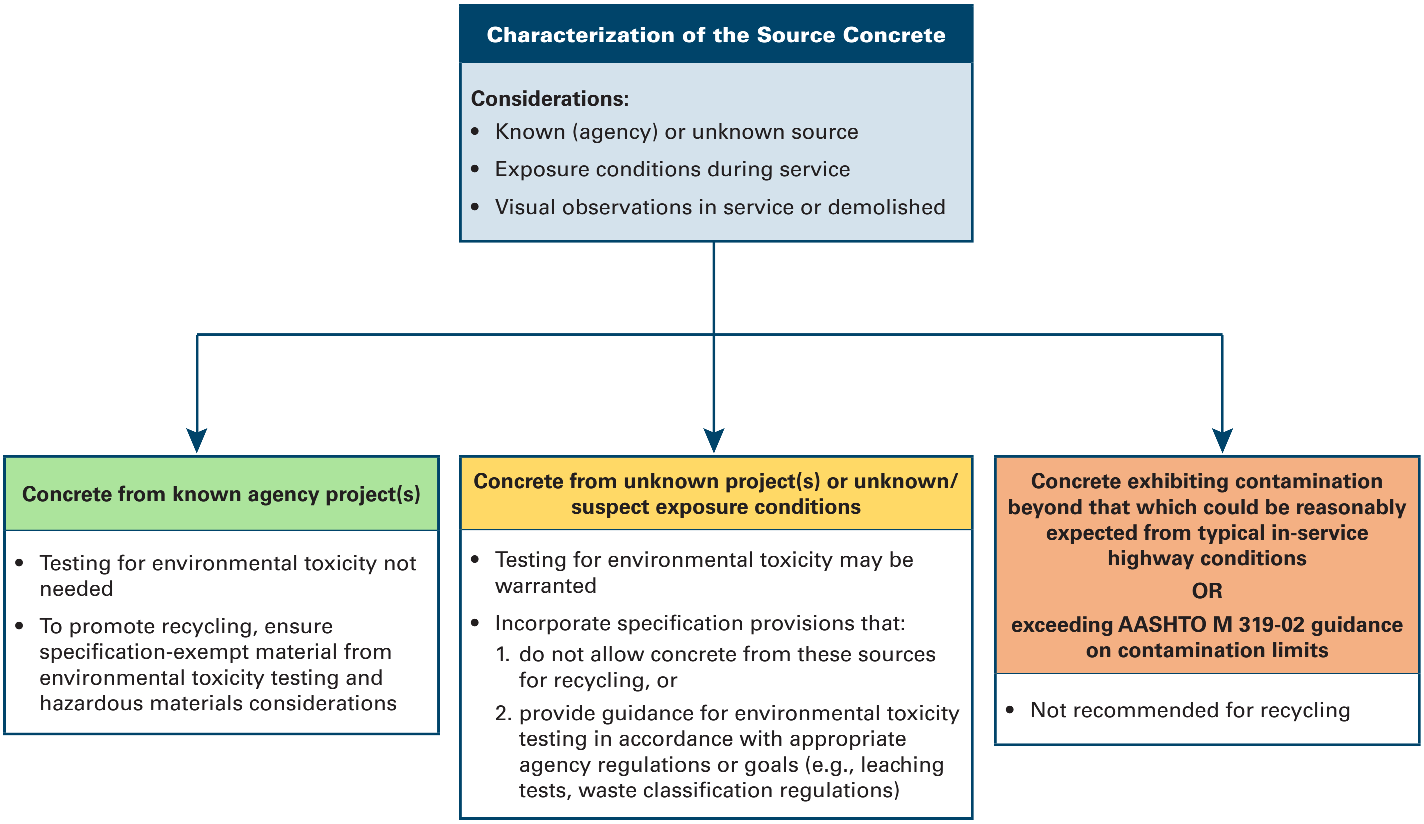
Recycled materials often contain minor amounts of contaminants and/or pollutant materials (Schwab et al. 2014). Concrete from building and demolition debris can include contaminants that could be problematic (e.g., asbestos). However, by using concrete from known sources, such as existing agency infrastructure, the likelihood of contaminants is highly reduced.

Chemicals, metals, sealants, and other materials present in highway concrete used for recycling could also become pollutants. However, these contaminants are not generally present in appreciable amounts (NHI 1998), and over the decades of service of many projects using RCA, **environmental impacts associated with contaminated source concrete from bound or unbound applications have not been reported.**

A flowchart showing recommended actions for concrete sourced from different projects is shown in Figure 2.

Table 1. Planning considerations and design techniques that protect water quality

RCA Use	Consideration	Mitigation Strategies
Unbound bases	Contamination/pollutants from the source concrete	• Use of concrete from known agency sources • Pre-qualification of source material
	High-pH leachate	• Place drainage outlets away from receiving waters • Use hardy vegetation and bioswales near drain outlets • Consider temporary use of pH adjustment products, such as pH (“shock”) logs, at potentially problematic locations (after construction)
	Pollutants in leachate	• Construct drains away from receiving waters • Utilize bioswales or mechanical sediment traps
	Sediments and solid precipitate	• Use daylighted bases • Pre-qualify geotextile fabric per AASHTO M 319-02 • Wrap trench (rather than pipe) in geotextile fabric • Consider eliminating rodent screens • Consider blending RCA with natural aggregate • Utilize mechanical sediment traps at outlet structures • Utilize chemical coagulant products, such as “floc” logs, at local problematic locations (after construction)
Fill (beneficial reuse of fines)	High-pH leachate	• Construct away from receiving waters • Utilize hardy vegetation and bioswales in surrounding area
	Pollutants in leachate	• Construct away from receiving waters
New RCA concrete mixtures	Contamination/pollutants from the source concrete	• None required



Characterization of the Source Concrete

Considerations:

- Known (agency) or unknown source
- Exposure conditions during service
- Visual observations in service or demolished

Concrete from known agency project(s)

- Testing for environmental toxicity not needed
- To promote recycling, ensure specification-exempt material from environmental toxicity testing and hazardous materials considerations

Concrete from unknown project(s) or unknown/ suspect exposure conditions

- Testing for environmental toxicity may be warranted
- Incorporate specification provisions that:
  1. do not allow concrete from these sources for recycling, or
  2. provide guidance for environmental toxicity testing in accordance with appropriate agency regulations or goals (e.g., leaching tests, waste classification regulations)

Concrete exhibiting contamination beyond that which could be reasonably expected from typical in-service highway conditions

OR

exceeding AASHTO M 319-02 guidance on contamination limits

- Not recommended for recycling

Figure 2. Recommended actions for qualification of source concrete to protect water quality

If concrete for recycling is sourced from an agency project (or projects), testing for environmental toxicity is not recommended—and incorporating specification provisions stating this policy may encourage concrete recycling. An example of such a consideration is in the Washington State Department of Transportation (WSDOT) specifications, which exempt recycled materials obtained from the WSDOT's roadways from toxicity testing and certification for toxicity characteristics (WSDOT 2015).

For concrete sourced from unknown projects, or projects with unknown or suspect exposure conditions, some common tests to evaluate the suitability for use as RCA may be warranted. For known projects, review of service history and/or visual observations of the material may provide evidence of whether contamination is an issue.

Some states have specified tests such as total lead content testing or the toxicity characteristic leaching procedure (TCLP) if concrete is to be sourced from non-agency or unknown sources. Test results could be compared to requirements for dangerous wastes and, if not classified as such, should be considered for recycling.

Concrete exhibiting contamination during a visual inspection or suspected to be exposed to harmful substances during its service life should not be considered for recycling. AASHTO M 319-02, Standard Specification for Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course, also provides limits on contaminants in the RCA, provisions for stockpile management to prevent contamination, and guidance for assessment of RCA, including lot/sublot descriptions and sizes to facilitate testing and acceptance (AASHTO 2010).

Mitigating Water Quality Concerns for RCA Leachate

It is important to note that most projects that include RCA have provided long-term service without water quality issues. However, water quality issues have been very infrequently reported at isolated locations at some concrete recycling projects. RCA characteristics vary by site, as do pavement drainage characteristics and local conditions adjacent to drain outlets.

Pre-qualification of source material (known vs. unknown sources) can reduce the potential for contaminants

Studies have consistently shown that the leaching characteristics (i.e., concentrations, release mechanisms, and timing) of many elements, including heavy metals and other ions of interest for water quality, depend on pH, temperature, and the ability of the contaminant to bind with components of the RCA (Engelsen et al. 2010, Mulugeta et al. 2011, Chen et al. 2012, Edil et al. 2012). However, the characteristics of RCA leachate measured in laboratory tests have often differed from the characteristics of RCA leachate obtained from field sites (Qin and Yang 2015).

The pH of RCA leachate measured in the laboratory using traditional column leaching tests is typically fairly high (often in the range of pH 10 to 13). Although often initially high, RCA leachate from field sites tends to return to a relatively neutral pH in the long term (often in the range of pH 6 to 8 within a few months or years of service) and is acceptable for discharge (Sadecki et al. 1996, Edil et al. 2012, Engelsen et al. 2012). Infiltration and exposure to soils, vegetation, and rock aid in pH neutralization and binding of ionic components.

The lower pH values typically measured in field-obtained leachate have been attributed to changes in the RCA over time due to carbonation and additional hydration of cement in the RCA. Changes in the RCA are dependent upon many factors, including composition, gradation, exposure to moisture, and compaction (Engelsen et al. 2012, Edil et al. 2012, Chen et al. 2013, Qin and Yang 2015, Galvin et al. 2014, Abbaspour et al. 2016).

The characteristics of leachate from unbound RCA vary over time based on RCA composition, gradation, exposure to moisture, and other factors

Placement of a dense portland cement concrete or an asphalt cement concrete pavement layer above unbound RCA will slow carbonation, altering the rate of change of leachate pH, and subsequently the release of pH-dependent constituents (Engelsen et al. 2010, Qin and Yang 2015).

Ongoing research is being performed to gain a better understanding of the leaching characteristics of in-service unbound RCA bases and to provide additional guidance for BMPs around stockpiles and in unbound applications (Townsend et al. 2016, Ginder-Vogel 2017).

Strategies implementable during project planning and design (as summarized in Table 1) have been shown to successfully mitigate water quality concerns for almost all in-service projects with unbound RCA base. Most importantly, ensuring that subsurface drain outlet locations are adequately separated from receiving waters is a measure that will prevent many issues.

Use of hardy vegetation near subsurface drainage outlets is also suggested. Bioswales have been successfully utilized as biological treatment features to neutralize alkaline runoff and capture sediments at outlets close to receiving waters. For example, the Illinois State Toll Highway Authority has included a provision in their *Drainage Design Manual* stating that "Subsurface drain outlets shall not be located within 200 feet upstream of the eventual watercourse. This allows the necessary spacing for the construction of any biological treatment feature downstream from the outlet to treat fine material which may wash out from the RCA." (Illinois Tollway 2017)

If outlets must be constructed closer than 200 feet from a watercourse, the designer is directed to provide space for a mechanical sedimentation trap to be constructed to capture the RCA fines (Illinois Tollway 2017).

If high-pH or sediment-laden leachate is present after construction at isolated locations, commercial products such as pH (or "shock") logs and chemical coagulant (or "floc") logs have been utilized as a temporary measure until acceptable leachate characteristics are achieved (Wagner 2017).

Some soils have been shown to successfully reduce the pH of alkaline runoff and leachate, and ongoing research in this area is focused on the development of practical solutions to runoff and leachate from RCA (Townsend et al. 2016, Ginder-Vogel 2017).

Preventing Drainage Issues from Sediments and Solid Precipitate

In unbound applications, RCA is capable of producing precipitate (i.e., calcium carbonate) and insoluble residue or "crusher dust." Calcium salts and calcium hydroxide from RCA are soluble, and calcium-based mineral deposits (often referred to as tufa) form when these minerals come out of the solution. Formation of this deposit is affected by the minerals present, temperature, and the presence of carbon dioxide (Bruinsma and Snyder 1995).

Runoff from all RCA can produce sediments and solid precipitates. However, the potential for tufa formation appears to be related to the amount of freshly exposed cement paste and increases with surface area (smaller particles) and higher paste content.

Washing RCA may reduce the potential for accumulation of dust and other fines but does not greatly reduce the potential for tufa formation (Bruinsma and Snyder 1995). When RCA is used in drained layers, these deposits can affect the permeability of geotextile fabrics, drainable bases, drainage pipes, or other drainage features downstream of the RCA base (AASHTO 2010); this is not usually a problem when RCA is used in undrained layers or layers below the drains.

Drainage outlets with rodent screens can be more readily affected than drainage outlets without rodent screens (Ceylan et al. 2014).

In general, precipitate formation and sediment deposit does not occur at all sites, and systems with some tufa formation are functioning adequately at many sites. For example, a Minnesota Department of Transportation (MnDOT) field study showed that precipitate and insoluble residue were not observed in most drainage systems in amounts that would significantly reduce the flow capacity (Snyder and Bruinsma 1996).

The researchers also found that, although precipitate can reduce permeability of drainage filter fabrics, pipe drains that are unwrapped and placed in drain trenches backfilled with permeable granular materials (as shown in Figure 3) functioned better than those with wrapped pipes in similar trenches.

In more recent field observations to support research conducted for the Iowa Department of Transportation (DOT), Ceylan et al. (2014) found less tufa formation from RCA base in drainage systems where polyvinyl chloride (PVC) outlet pipe is used without rodent guards and blends of RCA and virgin materials are utilized. **The researchers concluded that "tufa from RCA materials does not need to be mitigated or removed through any alternative solutions, such as RCA material quality control, outlet design, maintenance, etc."** (Ceylan et al. 2014)

Design and construction considerations to mitigate drainage structure clogging can be incorporated into edge drain design (see Figure 3), or a daylighted subbase could be considered (see Figure 4).

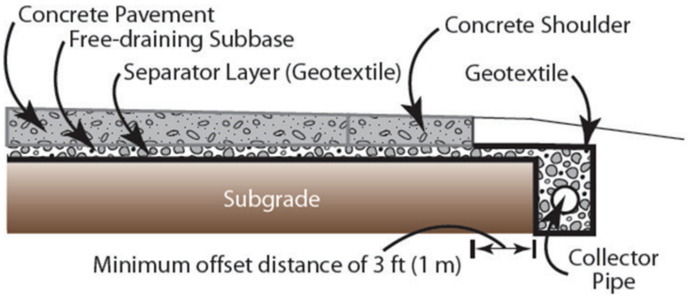


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Figure 3. Typical edge drain piping to minimize precipitate formation and sediment deposit

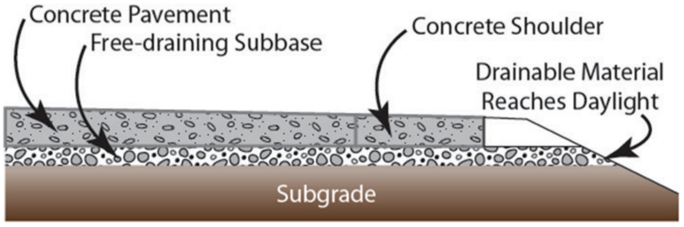

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Figure 4. Typical daylighted subbase

Additionally, fabrics with higher permittivity that can withstand significant amounts of precipitate deposits and still facilitate adequate flow can be utilized (Snyder and Bruinsma 1996).

A resource for design and specification considerations to mitigate potential negative environmental impacts of RCA in unbound bases is AASHTO M 319-02. Specifically, Section X2, Tufa-Like Deposits, of this specification provides guidance on validating geotextile or fine-grained drainage layers by field experience and comparative permeability testing to mitigate impacts of deposit formation.

Additional provisions to prevent formation of deposits and sediments include those aimed at minimizing fines and blending RCA with virgin materials, although Bruinsma and Snyder (1995) suggested that selective grading with natural aggregates may reduce, but not prevent, tufa formation.

Guidance and Training

Guidance on mitigating water quality issues is provided by the U.S. Environmental Protection Agency (EPA) in *Developing Your Stormwater Pollution Prevention Plan* (EPA 2007). This publication provides information and tools to assist with stormwater pollution prevention plan (SWPPP) development and implementation, including site assessment and planning, selection of BMPs, inspection, maintenance, recordkeeping, and final stabilization.

BMP details for water and air pollution protection related to the production and use of RCA can be provided in project drawings or special provisions, and agency guidance documents for implementing and maintaining BMPs are helpful tools for ensuring stakeholders understand permissible (and unacceptable) activities associated with recycling.

Personnel training is also an important component of programs for preventing adverse environmental impacts. Agencies can integrate information on concrete recycling and mitigation of environmental concerns into existing training courses and seminars for stormwater and erosion control.

On a project basis, strategies for mitigating environmental impacts associated with RCA (along with plans for monitoring and oversight) should be discussed at pre-construction and construction progress meetings.

Summary

Although it is an inherently sustainable practice, concrete recycling should be approached in a manner that prevents or mitigates potential adverse environmental impacts. Controls readily implementable during planning and design (discussed in this technical brief) and during construction (discussed in Cavalline 2018) have been consistently shown to mitigate water quality issues associated with use of RCA.

Concrete recycling has been successfully performed in many highway projects without adversely affecting the environment. Use of appropriate design and construction controls to mitigate environmental impact is simply another step in treating RCA as an engineered material, ensuring a more sustainable highway infrastructure.

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