APPENDIX H

Superpave Design Guidelines for Using Hot-Mix Recycled Asphalt Pavement and Recycled Asphalt Shingles

Recycling Hot-Mix Asphalt and Recycling Manufacturer Waste Asphalt Roofing Shingles General Guidelines

Producing quality hot-recycled asphalt pavement or producing quality asphalt pavement containing recycled manufacturer waste asphalt roofing shingles is most successful when “best practices” are followed. Today, through many years of experience and technological improvements using Recycled Asphalt Pavement (RAP) and experience starting in the mid-1990’s using Recycled Asphalt Shingles (RAS), recommended practices and procedures can be found in numerous publications regarding use of RAP and RAS. To assist new or less experienced personnel involved in the review, testing, design or production of hot-recycled asphalt mixtures, several comprehensive references are provided herein. By becoming familiar with such best practices, one should be more able to avoid potential problems affecting quality; more effectively address recognized existing problems affecting quality, and provide better assurance of consistent quality hot-mixed asphalt being produced cost-effectively. Recommended publications are referenced below and the publication may be obtained by contacting the publishers directly as noted.


“Recycling Hot Mix Asphalt Pavements,” Informational Series (IS) 123, Revised 1/2007, National Asphalt Pavement Association, NAPA Building, 5100 Forbes Blvd., Lanham, MD 20706-4407. Tel: (301-731-4748). This publication is available for purchase on the Internet at http://www.hotmix.org and following the link for “Online Store”.

“Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method: Technician’s Manual,” NCHRP Report 452, 2001, Transportation Research Board, National Research Council, Business Office, 500 Fifth Street N.W., Washington D.C. 20001. Tel: (202-334-3213); or email TRBsales@nas.edu. This publication is also available on the Internet at http://www.trb.org and following the links for “Online Documents” and “NCHRP Project Reports”.

“Designing HMA Mixtures with High RAP Content, A Practical Guide”, Quality Improvement Series (QIS) 124, Printed 3/2007, National Asphalt Pavement Association, NAPA Building, 5100 Forbes Blvd., Lanham, MD 20706-4407. Tel: (303) 731-4748. This publication is available for purchase on the Internet at http://www.hotmix.org and following the link for “Online Store”.


...
Proper mix design of an asphalt mixture containing RAP must give consideration to the amount of RAP and the amount and characteristics of the asphalt binder of the RAP in the mix. This is important as the effect of the RAP and its asphalt binder on the mix properties become more noticeable with an increase in the RAP content. Most recent recommendations, especially those by NCHRP Report 752, define the magnitude of RAP in the mixture based on the RAP asphalt binder content rather than the percent of RAP in the mixture. NCHRP Report 752 recommends a new term referred to as RAP Binder Ratio (RBR) to be used in deciding the level of contribution of the RAP to the mixture. RBR is defined as the ratio of RAP asphalt binder in the mixture to the total asphalt binder in the mixture. For example, if the total asphalt binder in the mixture is 5% and the RAP asphalt binder is 1% of this total, then RBR would be 0.20 (1 divided by 5). NCHRP Report 752 considers mixtures with RBR equal to or greater than 0.25 (i.e. RBR ≥ 0.25) as high RAP content mixtures. As RAS is also allowed in PennDOT asphalt mixtures, the RAS asphalt binder content also needs to be considered in deciding the mix design level. For this reason and hereafter in this document, RBR is used to represent the term Reclaimed Binder Ratio or Reclaimed Asphalt Binder Ratio rather than RAP Binder Ratio.

Mix design is considered in three tiers based on the total Reclaimed Asphalt Binder Ratio (RBR), as shown in Table H-1.

### Table H-1
Different Design Levels Based on RBR

<table>
<thead>
<tr>
<th>Mix Design Tier</th>
<th>Pavement Course(s)</th>
<th>RBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Wearing and Binder</td>
<td>≤ 0.20</td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>≤ 0.25</td>
</tr>
<tr>
<td>II</td>
<td>Wearing and Binder</td>
<td>&gt; 0.20 and &lt; 0.25</td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>&gt; 0.25 and &lt; 0.30</td>
</tr>
<tr>
<td>III</td>
<td>Wearing and Binder</td>
<td>≥ 0.25</td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>≥ 0.30</td>
</tr>
</tbody>
</table>
TIER 1 DESIGN PROCEDURE
(MIXTURES CONTAINING )UP TO AND INCLUDING 15% RAP OR
MIXTURES CONTAINING 5% RAS)

1. Sampling and Preparation (See Note 1)
   a. Obtain 5 to 10 representative samples of the reclaimed asphalt pavement (RAP) material or milled material or obtain 5 to 10 representative samples of the manufacturer waste recycled asphalt shingles (RAS) from different locations in the each stockpile using the mini-stockpile method. The number of increments selected, should be based on the estimated variability and size of the existing stockpile. Coordinate and receive concurrence from the District Materials Engineer/Manager (DME/DMM) on the minimum number of representative samples to obtain. The RAP or RAS material to be sampled must be representative of the RAP or RAS material used in production (i.e. The RAP is to be crushed, broken or screened the same as would be entered into the mix. The RAS is to be shredded, screened and perhaps blended with virgin aggregate the same as would be entered into the mix.). When RAP or RAS consists of large quantities from different sources, it is recommended to keep stockpiles separated and identified by source. However, with proper management, uniform RAP can be produced using crushing and screening operations, and uniform RAS can be produced using shredding, screening and perhaps blending operations, to process RAP and RAS coming from different sources. Each RAP material sample should consist of at least 30 lbs, (14 kg) of RAP or 2 lbs. (≈ 1 kg) of RAS. Obtain more RAP material for each sample if it is needed to complete all the required testing. For Tier 1 RAP design, each RAP material sample is not required to be split.
   b. Break up the RAP or RAS into small pieces similar to the AASHTO T 209 sample preparation procedure.
   c. Scalp the RAP or RAS over the same size sieve being used during production for the mix being designed.
   d. Dry all samples to a constant mass at 50º C. Do not overheat.

2. RAP or RAS Gradation and Asphalt Content (n=5 to 10)
   a. Determine the RAP or RAS asphalt content using PTM No. 757 Section 5 or PTM No. 702 (use a specific gravity of 1.030 for the asphalt cement). PTM No. 702 is the referee method if results are questionable or greater accuracy and reliability are desired.
b. Determine the aggregate gradation using **PTM No. 757 AASHTO T 30** (when PTM No. 757 is used) or **PTM No. 739** (when PTM No. 702 is used).

c. Average the test results (n=5 to 10) for asphalt content and gradation. Use the average values for design. Calculate the averages and standard deviations for asphalt content and gradation (percent passing on each sieve size) based on ten (10) samples. Ensure the RAP stockpile meets the standard deviation requirements of Section 409, Table 1. Use the average values for asphalt content and gradation in the mixture design.

3. **Determination of the RAP or RAS Aggregate Bulk Specific Gravity (G_{sb})**

Either of the following two methods may be used to establish RAP Aggregate Bulk Specific Gravity (G_{sb}).

a. **Method A:** RAP aggregate extracted according to PTM No. 702 is used to conduct AASHTO T 84 and T 85 procedures for the fine and coarse aggregates, respectively. The combined G_{sb} of the coarse and fine aggregate is used as the RAP G_{sb}. Calculate the combined G_{sb} using the individual fine and coarse aggregate G_{sb} values and the percent of the fine and coarse aggregate in the total extracted aggregate in a weighted average formula.

b. **Method B:** Use the theoretical maximum specific gravity, the aggregate effective specific gravity, and binder absorption to determine G_{sb} of the RAP or RAS through aggregate through the following steps and use as the bulk specific gravity for the mix design.

i. **Determine RAP theoretical maximum specific gravity.**

- Combine the remaining material from the original samples (n=5 to 10) mixing thoroughly as stated in AASHTO T 248.
- Quarter the combined material in accordance with AASHTO T 248. There will be four samples after combining and quartering.
- Split each quarter according to AASHTO T 248 to obtain the correct sample mass required for a theoretical maximum specific gravity test using AASHTO T 209.
- Determine the theoretical maximum specific gravity (G_{mm}) of each sample (n=4) using AASHTO T 209 as modified in Appendix I herein. Before performing the G_{mm} test on RAP or RAS, it is important that the RAP or RAS is prepared as follows:
  1. **Dry Heat** the test sample to constant mass in a forced draft oven at 410 ± 35°C (750 ± 9°F) until the RAP asphalt binder is softened or maximum 2 hr. ± 5 min.
  2. Break up the sample similar to a standard G_{mm} sample.
  3. Mix the RAP or RAS sample thoroughly to allow the old RAP or RAS binder to coat the uncoated aggregate particles.
a. ii. Determine the effective specific gravity ($G_{se}$) for each sample using the following formula:

$$G_{se} = \frac{(100 - P_b)}{\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)}$$

where:
- $G_b = \text{(binder specific gravity)} = 1.030$ (assumed)
- $P_b = \text{Average Percent Asphalt content of (n=5 to 10) RAP samples}$
- $G_{mm} = \text{Theoretical Maximum Specific Gravity of RAP}$

Average the $G_{se}$ of the four quarters. This is considered as the RAP aggregate effective specific gravity. Use this value as the $G_{sb}$ for the mix design.

iii. Determine the binder absorption ($P_{ba}$) in one of two ways:

1. Using historical data of the region, assume a reasonable level of absorption for the RAP aggregate ($P_{ba}$). The District Materials Engineer/Manager must approve this method and the assumed value for $P_{ba}$.

2. Using RAP extracted aggregate from PTM No. 757, conduct AASHTO T 84 and T 85 procedures on the fine and coarse aggregate portions of the extracted aggregate, respectively. Blend another sample of extracted aggregate from PTM No. 757 with a PG 76-22 (PG 64E-22) binder at the RAP average asphalt content and determine $G_{mm}$ of this blended mix. Then, use Equation 2 to determine $G_{se}$ of the extracted RAP aggregate. Notice this is the same as Equation 1, except that a different $G_{mm}$ is used.
\[ G_{se} = \frac{(100 - P_b)}{\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)} \]

where:
\( G_{se} = \) effective specific gravity of the extracted RAP Aggregate (from PTM No. 757)
\( G_{mm} = \) maximum theoretical specific gravity of the blend of the extracted RAP aggregate and the PG 76-22 (PG 64E-22) binder

Then, percent binder absorbed into the RAP aggregate (\( P_{ba} \)) is calculated from Equation 3.

\[ P_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{se} \times G_{sb}} \times G_b \]

where:
\( G_{se} = \) the effective specific gravity of the extracted RAP Aggregate from Equation 2.
\( G_{sb} = \) the combined bulk specific gravity of the RAP extracted aggregate (from PTM No. 757) determined from AASHTO T 84 and T 85.

iv. Find the RAP aggregate bulk specific gravity (\( G_{sb} \)) using Equation 4.

\[ G_{sb} = \frac{G_{se}}{P_{ba} \times G_{se} + 1} \]

where:
\( G_{se} = \) the original effective specific gravity of the RAP from Equation 1 (Section 3.b.ii.)
\( P_{ba} = \) assumed from historical data of the region (Section 3.b.iii.1) or calculated from Equation 3 (Section 3.b.iii.2).

4. Combined Bulk Specific Gravity of Aggregate (\( G_{sb} \))

—Calculate the combined aggregate bulk specific gravity (RAP or RAS aggregate and virgin aggregate) using the \( G_{se} \) and \( G_{sb} \) of the RAP aggregate and the \( G_{sb} \) of the virgin aggregate considering their proportions in the blend or RAS as the \( G_{sb} \). Use only the aggregate percentage of the RAP or RAS. The following example shows how to determine the contribution of RAP aggregate in calculation of combined bulk specific gravity.

Example 1: 10% RAP is used as 20% of total mix. With 6.0% average asphalt content of RAP is 5.0% based on the test results from 10 samples, tested and averaged, the aggregate contribution is 9.4% and In that case, the asphalt contribution from
RAP is 0.61.0% of the total mix (i.e., 0.20 X 5.0%), and the contribution from RAP aggregate is 19.0 % (i.e., 0.20*95.0%). If the virgin aggregate is 75% of the total mix, then RAP aggregate percent for determination of combined gravity will be 20.2% (Divide 19 by sum of 19 and 75).

Example 2: 5% RAS with 20% asphalt content based on the 10 samples tested and averaged, the aggregate contribution is 4.0% and the asphalt contribution is 1.0% of the total mix.)

5. Preparation of Mixture Specimens

a. Heat the mixture containing the RAP or RAS and virgin aggregate to the mixture temperature. Weigh the RAP or RAS as a completed mass or as sieve size fractions and add to the virgin aggregate. Heat the combined virgin aggregate and RAP or RAS to the required mixing temperature in accordance with AASHTO T 312. The mixture should be held at the mixing temperature for more than one 1½ to 3 hours. Calculate the weight of virgin asphalt to be batched (the weight of asphalt required at the individual asphalt content minus the weight of asphalt included in the RAP or RAS) and add to the heated aggregate and RAP or RAS.

b. After laboratory mixing and prior to compaction, short-term aging or mixture conditioning is required the same as for a virgin mixture. (AASHTO T 209 mixture conditioning as modified in Appendix I herein).

6. Apparent Specific Gravity (Gsa) and Water Absorption (w) of RAP or RAS Material

Use the Gse calculated for the RAP or RAS as the apparent specific gravity (Gsa) and water absorption (w) of RAP aggregate can be determined three ways:

I. If Method A (Section 3.a) is used to determine Gsb, then the test results will also be used to determine Gsa and water absorption (w).

II. If Method B (Section 3.b) is used, and binder absorption is assumed to be a known value, as explained under Method B (Section 3.b.iii.1), then Gsa and water absorption (w) are determined using Equations 4 and 5, respectively.

\[
G_{sa} = 2G_{se} - G_{sb} \quad \text{Equation 4}
\]

\[
w = \frac{G_{sa} - G_{sb}}{G_{sa} \times G_{sb}} \times 100 \quad \text{Equation 5}
\]

where:

- \(G_{se}\) = RAP aggregate effective specific gravity from Method B (Section 3.b.i.)
- \(G_{sb}\) = Aggregate bulk specific gravity from Method B (Section 3.b.iv.)
- \(w\) = water absorption in percent
III. If Method B of Section 3 is used, and Section 3.b.iii.2 is followed, then water absorption ($w$) found from AASHTO T 84 and T 85 will be used to determine $G_{sa}$ as given in Equation 6.

$$G_{sa} = \frac{100G_{sb}}{100 - wG_{sb}}$$  \hspace{1cm} \text{Equation 6}$$

and assume 0% absorption for the RAP or RAS material (See Note 3).

where:

$w$ = the RAP aggregate water absorption in percent from AASHTO T 84 and T 85, as explained in Section 3.b.iii.2, under Method B.

$G_{sb}$ = the RAP aggregate bulk specific gravity from Method B (Section 3.b.iv.)

7. Consensus Properties

Use only the consensus properties of the virgin aggregate. Consensus properties (AASHTO M 323 Table 5) are waived on the RAP or RAS aggregate, except that Crush count requirements on the coarse aggregate will be required for RAP designs with traffic levels $\geq 30$ million ESALS. This requirement is for wearing and binder courses. Base course mixes are excluded from crush count requirement for RAP aggregate. to assure crush requirements are met, unless mix is a base course. (See AASHTO R 35 Subsection 8.3 Notes 9 and 10).

8. LTS PG Binder Grade Evaluation and Mixture Virgin Binder Grade

LTS PG binder grade evaluation is not required for Tier 1 design procedure. The performance grade of the virgin asphalt binder used under Tier 1 must be the target or specified grade of asphalt binder in the asphalt mixture.

8.9. Mix Design

a. $A \leq 15\%$ RAP mix design under Tier 1 or a 5% RAS mix design is may be formulated based on an approved virgin mix design and similar in composition (asphalt content and gradation) to the virgin design. A one-point design (See Note 42) may be sufficient for submission of the mix design for review, if the following occurs. The resulting air void content of the RAP and virgin blend or the RAS and virgin blend shall be 4% ± 0.1% at design number of gyrations. If the air void content is between 3.5% and 3.9%, or 4.1% and 4.5%, for the initial trial, then adjust the asphalt content accordingly in order to obtain the 4.0% air void content at design number of gyrations. If a 4.0% ± 0.1% air void content can be achieved by adjusting the asphalt content and the RAP or RAS mixture meets all the requirements in Chapter 2A (excluding Table 5. Superpave Aggregate Consensus Property Requirements), the one-point mix design may be submitted for approval. However, if the air void content is less than 3.5% or greater than 4.5% (based on initial testing at the optimum asphalt content of the virgin mix design) then a complete mix design produced in accordance with Chapter 2A is required.

b. After optimum asphalt content has been determined, perform moisture sensitivity testing according to the modified version of AASHTO T 283, as described required in Chapter 2A.
10. **Mixture Performance Tests**

Mixture performance tests are not required for Tier 1 design procedure.

9.11. **Design Submittal**

In accordance with Publication 408, submit to the District Materials Engineer/Manager the following:

**RAP or RAS Mix Design Information:**

- Producer’s Bituminous Job Mix Formula (JMF). Submit through eCAMMS.
- Table 4H-3, as presented at the end of this appendix, showing the gradations, asphalt contents, and averages and standard deviations. Submit through eCAMMS as a JMF Attachment.
- TR 448 Completed and Signed.
- Volumetric Testing Summary. Submit through eCAMMS as a JMF Attachment.
- Moisture Sensitivity Testing Summary. Submit through eCAMMS as a JMF Attachment.

**Virgin Mix Design Information, If Applicable** (Mix Used as Basis for RAP or RAS Design):

- TR 448A of previously completed, reviewed and signed virgin design. Submit through eCAMMS as a JMF Attachment.
- Moisture Sensitivity Testing Summary of previously completed, reviewed and signed virgin mix design. Submit through eCAMMS as a JMF Attachment.
## TABLE 1. RECYCLED ASPHALT PAVEMENT OR RECYCLED ASPHALT SHINGLES MIX

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>(Check One) RAP  or RAS  Grading and AC Content</th>
<th>Average RAP/RAS Gradation &amp; AC Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. 1  No. 2  No. 3  No. 4  No. 5  No. 6  No. 7  No. 8  No. 9  No. 10</td>
<td></td>
</tr>
<tr>
<td>2&quot; (50mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>1 1/2&quot; (37.5mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>1&quot; (25mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>3/4&quot; (19mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>1/2&quot; (12.5mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>3/8&quot; (9.5mm)</td>
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<tr>
<td>#4 (4.75mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>#8 (2.36mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>#16 (1.18mm)</td>
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</tr>
<tr>
<td>#30 (0.600mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>#50 (0.300mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>#100 (0.150mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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<tr>
<td>#200 (0.075mm)</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
</tr>
<tr>
<td>Asphalt Content</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
<td>.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .</td>
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</tbody>
</table>

Notes: __________________________________________

Technician __________________________
TIER 2 DESIGN PROCEDURE

For Tier 2 design procedure, follow the Tier 1 design procedure, except as revised and modified for each of the steps as follows.

(MIXTURES CONTAINING GREATER THAN 15% RAP or MIXTURES CONTAINING 5% OR MORE RAP AND 5% RAS)

1. **Sampling and Preparation** *(See Note 1, page H-1)*

Follow sections 1.a through 1.d as explained under Tier 1 except each RAP material sample collected under section 1.a should consist of at least 60 lbs. of RAP material. Obtain more RAP material for each sample if it is needed to complete all the required testing and to split each sample as required. Then, continue with the additional following sections 1.e. to 1.g and continue as follows:

**e.** Obtain 5 to 10 representative samples of the reclaimed asphalt pavement (RAP) material or milled material from different locations in the stockpile using the mini-stockpile method. If combining ≥ 5% RAP with 5% manufacturer waste recycled asphalt shingles (RAS), obtain 5 to 10 representative samples of the processed RAS from different locations in the stockpile using the mini-stockpile method. The number of increments selected, should be based on the estimated variability and size of the existing stockpile. The RAP and, if used, RAS, material that is to be sampled must be representative of the RAP and RAS product used in production (i.e., The RAP is to be crushed, broken, and screened the same as would be entered into the mix. The RAS is to be shredded, screened and perhaps blended with virgin aggregate the same as would be entered into the mix.). When RAP or RAS consists of large quantities from different sources, it is recommended to keep stockpiles separated and identified by source. However, with proper management, uniform RAP can be produced using crushing and screening operations, and uniform RAS can be produced using shredding, screening and perhaps blending with virgin aggregate operations, to process RAP and RAS coming from different sources. Each sample should consist of at least 60 lbs. (27 kg) of RAP and if used, 4 lbs. (~ 2 kg) of RAS.

**f.** Break up the RAP and if used, RAS (keeping it separated from the RAP) into small pieces similar to the AASHTO T 209 sampled preparation procedure.

**g.** Scalp the RAP and if used, RAS over the same size sieve used during production for the mix being designed.

**h.e.** Split each sample of the RAP and if used, RAS material collected from each RAP stockpile (total n=10 samples) into two equal portions of at least 30 lbs. of RAP material for each split keeping the RAP and RAS materials separated. Identify and label both split portions of each sample by the sample number and the split number (e.g., RAP 1A, RAP 1B, RAP 2A, RAP 2B, etc. and, if used, RAS 1A, RAS 1B).

**f.** Save one set of split samples a split sample of at least 30 lbs. (14 kg) of RAP and, if used, at least 2 lbs. (~ 1 kg) of the RAS to send to the and retain at the...
producer’s facility in case additional testing is requested by the Department. This material shall be retained for a period of one year.

i. Materials and Testing Division.

  g. **Retain Use** the other set of split samples at the plant for testing and designing the HMA mixture containing RAP or the HMA mixture containing both RAP and RAS.

  j. *(See Note 5)*
1. **Note 5** - When a design is anticipated to incorporate more than 20% RAP (>20%), or anticipated to incorporate greater than or equal to 10% RAP and 5% RAS, it is recommended that the mix design process required by the producer commence well in advance of the anticipated need for the proposed design, due to the potential length of time that may be required to achieve an approved mix design.

2. **RAP and If Used, RAS Gradation and Asphalt Content (n=5 to 10)**
   
   a. Follow the procedure beginning at Section 1.d2 of Tier 1 Design Procedure and continue following the procedure in Section 2, with the following exceptions: The RAP asphalt content must be determined using PTM No. 702 if >20% RAP is used. PTM No. 702 must be used to determine asphalt content when using 10% or more RAP and 5% RAS.

3. **PG Binder Grade Evaluation**
   
   e. Complete the information required in Table 1. Submit the split samples of RAP, the split samples of RAS (if used), 2 quarts of P.G. binder specified for mix application, TR 448 for the virgin mix design used as a basis for the RAP design or for the combined RAP and RAS design, proposed blend and JMF for the recycled design, and the completed Table 1 to the MTD for evaluation. If the design incorporates >20% RAP or incorporates both RAP and RAS, submit additional samples of P.G. binder that is one grade softer than the specified application.
   
   f. The MTD will evaluate the aged asphalt in the RAP and if used, RAS, after asphalt binder recovery, and will recommend the grade of virgin asphalt cement for recycling utilizing the procedure outlined in Figure 1 and additional criteria as deemed appropriate. When >20% RAP will be incorporated in a mix, or when both RAP and RAS will be incorporated in the mix, additional analysis will typically include: more thorough evaluation of recovered RAP and RAS (if used) binder properties, relative proportions of required virgin to RAP binder or, to RAP and RAS binder, estimated asphalt film thickness calculated for the proposed mix, more detailed evaluation of long-term aging effects on both volumetric mixture properties and moisture sensitivity, and finally, a statistical evaluation of recycled material component variability based on plant QC records.

4. **3. Determination of the RAP and RAS (If Used), Aggregate Bulk Specific Gravity (Gsb)**
   
   a. Follow the procedure in Section 3 of Tier 1 Design Procedure.

5. **4. Combined Bulk Specific Gravity of Aggregate (Gsb)**
   
   a. Follow the procedure in Section 4 of Tier 1 Design Procedure.
5. Preparation of Mixture Specimens

a. Follow the procedure in Section 5 of Tier 1 Design Procedure, however, note the following recommendations. Reduce the RAP by hand sieving over a 4.75 mm (No. 4) and a 2.36 mm (No. 8) sieve, resulting in the following three size fractions; the minus 2.36 mm (No. 8) sieve, the minus 4.75 mm (No. 4) sieve retained on the 2.36 mm (No. 8) sieve, and the plus 4.75 mm (No. 4) sieve material. This method can significantly reduce the potential for non-uniform or inconsistent mix composition of completed mix specimens, which can occur when using higher percentages of RAP. If RAS is included and not pre-blended with virgin fine aggregate, combine with the minus 2.36 mm (No. 8) sieve RAP material. (See Note 3 of Tier 1.)

6. Apparent Specific Gravity ($G_{sa}$) and Water Absorption ($w$) of RAP or RAS Material

a. Follow the procedure in Section 6 of Tier 1 Design Procedure.

7. Consensus Properties

a. Consensus properties (AASHTO M 323, Table 5) must be determined on the RAP extracted aggregate and mathematically combined with the virgin aggregate consensus properties in proper proportions or the combined blend of RAP extracted aggregate and virgin aggregate in accordance with the requirements in AASHTO R 35 (See Chapter 2A, Subsection 6.9 modification to Note 6). The consensus properties on the aggregate blend using either method must meet or exceed the required consensus properties for the ESAL range the mix design is intended for except as modified in AASHTO R 35 Subsection 8.3 Notes 9 and 10 and AASHTO M 323, Subsection 6.6, for RAP extracted aggregate or RAS sand equivalent. Assume RAS aggregate consensus properties are negligible unless combined with a virgin fine aggregate as described in Note 3 of Tier 1. In this case, determine consensus properties of the blended RAS aggregate and fine aggregate—PTM No. 757 cannot be used to obtain the extracted aggregate portion of the RAP used for the consensus property testing. PTM No. 702 is an approved method of obtaining the RAP extracted aggregate fraction.

8. LTS PG Binder Grade Evaluation and Mixture Virgin Binder Grade

LTS PG binder grade evaluation is not required for Tier 2 design procedure. The performance grade of the virgin asphalt binder used under Tier 2 must be one grade softer than the target or specified grade of asphalt binder, at both the high and low temperatures.

9. Mix Design

a. A >15% RAP-A mix design containing RAP under Tier 2 or, a combined RAP and RAS mix design, may be formulated based on an approved virgin mix design and similar in composition (asphalt content and gradation) to the virgin mix design. A >15% RAP-A mix design under Tier 2—or, a combined RAP and RAS mix design—requires additional work to evaluate the affect of the RAP or
combined RAP and RAS on the mixture volumetric properties and moisture sensitivity. Use Chapter 2A to develop the RAP or combined RAP and RAS mix design (Complete Design Procedure).

10. **Mixture Performance Tests**

Mixture performance tests are not required for Tier 2 design procedure.

11. **Design Submittal**

   a. In accordance with Publication 408, submit to the District Materials Engineer/Manager the following:

   **RAP Mix Design or Combined RAP and RAS Mix Design Information:**

   - Producer’s Bituminous Job Mix Formula (JMF). Submit through eCAMMS.
   - Table 4-H-3, as presented at the end of this appendix, showing the gradations, asphalt contents, and averages, and standard deviations. Submit through eCAMMS as a JMF Attachment.
   - TR 448 Completed and Signed by Producer.
   - Volumetric Testing Summary. Submit through eCAMMS as a JMF Attachment.
   - Moisture Sensitivity Testing Summary. Submit through eCAMMS as a JMF Attachment.

   **Virgin Mix Design Information, If Applicable (Virgin Mix Used as Basis for Tier 2 Design):**

   - TR 448A of previously completed, reviewed and signed virgin mix design. Submit through eCAMMS as a JMF Attachment.
   - Moisture Sensitivity Testing Summary of previously completed, reviewed and signed virgin mix design. Submit through eCAMMS as a JMF Attachment.

   b. If requested by the District Materials Engineer/Manager, the MTD will provide testing and analysis of the proposed design, with recommendations. When >20% RAP will be incorporated in a mix or, when 10% or more RAP and 5% RAS will be incorporated in a mix, additional analysis will typically include: evaluation of mix volumetric properties and moisture sensitivity, following simulated long-term aging of specimens and a statistical evaluation of recycled material component variability based on plant QC records.
TIER 3 DESIGN PROCEDURE

For Tier 3 design procedure, follow the Tier 2 design procedure, except as revised and modified for each of the steps as follows.

1. **Sampling and Preparation**

   Follow sections 1.a through 1.d as explained under Tier 1 except sampling must be conducted in the presence of a Department Representative and each RAP material sample collected under section 1.a should consist of at least 90 lbs. of RAP material. Obtain more RAP material for each sample if it is needed to complete all required testing and/or to split each sample as required. Then, continue with the additional following sections 1.e. to 1.g

   e. In the presence of a Department Representative, split each sample of the RAP material collected from each RAP stockpile (total n=10 samples) into three equal portions of at least 30 lbs. of RAP material for each split keeping the RAP materials separated. Identify and label each sample and each split portion by the sample number and the split number (e.g., RAP 1A, RAP 1B, RAP 2A, RAP 2B, etc.).

   f. Use the first set of the split samples (e.g., 1A, 2A, 3A, etc.) for producer development of the asphalt mixture design.

   g. Use the second set of the split samples (e.g., 1B, 2B, 3B, etc.) for independent laboratory testing of the extracted and recovered asphalt binder. These RAP material split samples must be packaged in aggregate bags and tied with security tags in the presence of the Department Representative before shipment to the independent laboratory. Randomly select at least three samples from this set of split samples (n=3). Send the three randomly selected samples of sufficient quantity to an AASHTO accredited independent laboratory for asphalt binder extraction and recovery testing according to AASHTO T 319, Performance Graded Asphalt Binder testing, as specified in AASHTO M 350, and for determining the continuous grading temperatures and continuous grading of the recovered asphalt binder according to AASHTO R 29, Section 6, Test Procedure for Grading an Unknown Binder or ASTM D7643 from each of the three (n=3) split samples of fully processed RAP material. Submit the independent laboratory’s complete PG binder test results used to determine the continuous grading temperatures and continuous grading of the extracted and recovered asphalt binder from the RAP material and the continuous grade of the recovered asphalt binder from the RAP material for each of the three (n=3) split samples to the District Materials Unit for submission to LTS.

   h. Use the third set of the RAP material split samples (e.g., 1C, 2C, 3C, etc.) for submission to LTS through the District Materials Unit. Submit these RAP material split samples, along with and at the same time as the Table H-3 information from the first set of split samples and the independent laboratory’s PG Binder test results of the extracted and recovered asphalt binder from the second set of RAP material split samples. Do not submit these split samples to the District Materials Unit for shipment to the LTS without the Table H-3 and independent laboratory’s PG binder test results. Do not submit these samples to LTS prior to the completion of
and reporting of both the producer Table H-3 testing and the independent laboratory PG Binder testing.

2. RAP Gradation and Asphalt Content (n=10)
   a. Follow the procedure at Section 2 of Tier 2 Design Procedure.

3. Determination of the RAP Aggregate Bulk Specific Gravity (Gsb)
   a. Follow the procedure at Section 3 under Tier 1, Method A.

4. Combined Bulk Specific Gravity of Aggregate (Gsb)
   a. Follow the procedure in Section 4 of Tier 1 Design Procedure.

5. Preparation of Mixture Specimens
   a. Follow the procedure in Section 5 of Tier 2 Design Procedure.

6. Apparent Specific Gravity (Gsa) and Water Absorption (w) of RAP Aggregate
   a. Follow the procedure in Section 6 of Tier 2 Design Procedure.

7. Consensus Properties
   a. Follow the procedure in Section 7 of Tier 2 Design Procedure.

8. LTS PG Binder Grade Evaluation and Mixture Virgin Binder Grade
   a. Using the first set of representative RAP material split samples, complete and submit the information required in Table H-3 to the LTS. Submit the AASHTO accredited independent laboratory continuous binder grading test results, and continuous binder grades for each of the three randomly selected samples (n=3) to the LTS. Submit the third set of representative RAP material split samples, 2 quarts of PG binder specified for the mix application, proposed blend and JMF for the recycled design, to the LTS. Submit all items together as one package to LTS. Do not submit RAP samples until the independent testing of the RAP binder is completed.

   b. The LTS will evaluate using the independent AASHTO accredited laboratory results, and will recommend the grade of virgin asphalt cement for recycling utilizing the procedure outlined in Figure 1 and additional criteria as deemed appropriate. The LTS may verify the independent laboratory results using the split samples submitted to LTS as part of Tier 3, Section 4.a. Differences between the LTS verification results and the independent laboratory results will be investigated. The investigation may result in the use of the LTS recovered binder test results. Further work under Tier 3 design includes thorough evaluation of recovered RAP binder properties, relative proportions of required virgin to reclaimed binder, estimated asphalt film thickness calculated for the proposed mix, more detailed evaluation of long-term aging effects on both volumetric mixture properties and
moisture sensitivity, and finally, a statistical evaluation of recycled material component variability based on plant QC records.

9. Mix Design

a. Follow the procedure in Section 9 of Tier 2 Design Procedure.

10. Mixture Performance Tests -  

a. Moisture Damage/Rutting Tests: For Tier 3 design, in addition to the moisture damage requirements of Chapter 2A, AASHTO T 324 (Hamburg Wheel-Track Testing) shall be performed to assess both moisture damage and rutting. In the case of AASHTO T 324, the criteria presented in Table H-2 shall be satisfied:

<table>
<thead>
<tr>
<th>Design ESALs (million)</th>
<th>Maximum Hamburg Rut Depth, (mm)</th>
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</thead>
<tbody>
<tr>
<td>&lt; 3</td>
<td>---</td>
</tr>
<tr>
<td>3 to &lt;10</td>
<td>10</td>
</tr>
<tr>
<td>10 to &lt;30</td>
<td>8</td>
</tr>
<tr>
<td>≥ 30</td>
<td>6</td>
</tr>
</tbody>
</table>

These criteria must be satisfied at 20,000 passes of the Hamburg wheel tracking and at a temperature of 122°F (50°C). Stripping inflection point (SIP) must be calculated and reported for information purposes only. Performance tests shall be conducted by an independent AASHTO accredited laboratory or as otherwise agreed by the Department. LTS may choose to conduct performance tests for the purpose of verification.

11. Design Submittal

a. In accordance with Publication 408, submit to the District Materials Engineer/Manager the following:

RAP Mix Design Information:

- Producer’s Bituminous Job Mix Formula (JMF). Submit through eCAMMS.
- Table H-3, as presented at the end of this appendix, showing the gradations, asphalt contents, averages, and standard deviations. Submit through eCAMMS as a JMF Attachment.
- Independent laboratory PG Binder testing of extracted and recovered asphalt binder from RAP Material. Submit through eCAMMS as a JMF Attachment.
- Volumetric Testing Summary. Submit through eCAMMS as a JMF Attachment.
- Moisture Sensitivity Testing Summary. Submit through eCAMMS as a JMF Attachment.
- Moisture Damage/Rutting Mixture Performance Testing Summary. Submit through eCAMMS as a JMF Attachment.
Virgin Mix Design Information, If Applicable (Virgin Mix Used as Basis for Tier 2 Design):

- TR 448A of previously completed, reviewed and signed virgin mix design. Submit through eCAMMS as a JMF Attachment.
- Moisture Sensitivity Testing Summary of previously completed, reviewed and signed virgin mix design. Submit through eCAMMS as a JMF Attachment.

**Note 3:** For mix design with RAP under Tier 3, it is recommended that the mix design process required by the producer commence well in advance of the anticipated need for the proposed design, due to the potential length of time that may be required to achieve an approved mix design.

**Note 4:** For mix design with RAP under Tier 3, if requested by the District Materials Engineer/Manager, the LTS will provide testing and analysis of the proposed design, with recommendations. Additional analysis will typically include: evaluation of mix volumetric properties and moisture sensitivity, following simulated long-term aging of specimens and a statistical evaluation of recycled material component variability based on plant QC records.

The required independent laboratory testing must be performed prior to any testing by LTS. Request for testing by LTS must include a justification. LTS testing will not be performed in lieu of independent testing.
Determine Required Blended Binder Grade (e.g. PG 64-22)

Determine Percentage of RAP & RAS in Mixture

Extract and Recover Binder from RAP and RAS

Test High Temperature of the Original Recovered Binder

Determine Properties of the Recovered Binder (High, Intermediate, and Low Critical Temperatures)

RTFO Aged Binder Test (High, Intermediate, and Low)

Solve for the Critical Temperatures of the Virgin Asphalt Using the Following Equation (High, Intermediate, and Low)

\[
T_{\text{virgin}} = \frac{T_{\text{blend}} - (%\text{RAP} \times T_{\text{RAP}}) - (%\text{RAS} \times T_{\text{RAS}})}{(1 - %\text{RAP} - %\text{RAS})}
\]

Where:
- \(T_{\text{virgin}}\) = critical temperature of the virgin asphalt binder,
- \(T_{\text{blend}}\) = critical temperature of the blended asphalt binder (final desired),
- \(%\text{RAP}\) = percentage of RAP expressed as a decimal (e.g., 0.30 for 30 percent),
- \(%\text{RAS}\) = percentage of RAS expressed as a decimal (e.g., 0.05 for 5%),
- \(T_{\text{RAP}}\) = critical temperature of the recovered RAP binder,
- \(T_{\text{RAS}}\) = critical temperature of the recovered RAS binder
Mix Design when Incorporating Recycled Asphalt Shingle (RAS)

1. The procedures covered in the preceding sections are applicable when RAP is incorporated into the asphalt mix. It is assumed that all of the RAP binder fully blends with the virgin binder. In the case of incorporating recycled asphalt shingles (RAS) into the asphalt mix, it is also assumed that there is full blending of the RAS binder with virgin binder.

2. Combination of RAS and RAP binders will be used to determine the Reclaimed Asphalt Binder Ratio (RBR). Once RBR is established, depending on where the RBR lands in regard to the design tier, the steps for that tier shall be followed.

3. In the case of a Tier 2 design using RAS, in the presence of a Department Representative, obtain and retain a ten (10) pound sample of RAS (approximately a 1-gallon metal can with lid completely filled) at the Producer’s facility in case the RAS material is requested.

Figure 1. Method A: Blending at known RAP and RBR, if used, RAS Content (virgin binder grade unknown)
by the Department for further testing. Wrap tape completely around the RAS sample container several times and have the Department Representative sign the tape. Retain the ten (10) pound sample of RAS for the entire mix design year unless sample is requested by the Department. The maximum time to retain the RAS sample will not exceed one complete mix design year and the sample can be discarded at the beginning of the next mix design year. If the same RAS stockpile will be used for multiple Tier 2 designs, retain only one (1) ten (10) pound sample of RAS to represent all mix designs.

4. In the case of a Tier 3 design using RAS, in the presence of a Department Representative, obtain split samples of the RAS approximately ten (10) pounds each for the Department Representative to submit to the LTS for determination of the RAS binder grade.

5. As specified in Pub. 408, Section 409.2(c)2., processed RAS shall be free of foreign materials. Existence of deleterious materials in RAS shall be limited to 0.5%. Examples of such materials include excessive dirt, debris, concrete, metals, glass, paper, rubber, wood, and plastic.

6. As specified in Pub. 408, Section 409.2(c)2., and for all design levels, limit RBR from contribution of RAS to < 0.20 for wearing/binder courses, and to < 0.25 for base courses.

Example:

- RAP content in total mix: 20%
- RAP binder content: 4.8%
- RAS content in total mix: 5%
- RAS binder content: 21.5%
- Mix total binder content: 6.6%

Determine RBR:

- RAP binder content in the mix = 0.2 X 4.8 = 0.96%
- RAS binder content in the mix = 0.05 X 21.5 = 1.08%
- Total binder contribution from RAP and RAS = 2.04%

\[ \text{RBR} = \frac{2.04}{6.6} = 0.31 \]

This places the mix in the Tier 3 design, and the procedure for Tier 3 must be followed. Since for Tier 3 design, the critical temperature of reclaimed binder must be determined, RBR for RAP and for RAS must be used separately in the equation for determination of the virgin binder critical temperature. For the example above, we will have

For RAP \( \text{RBR}_p = \frac{0.96}{6.6} = 0.15 \), and for RAS \( \text{RBR}_s = \frac{1.08}{6.6} = 0.16 \)

The equation for determination of critical temperature will be as
\[
T_c(\text{virgin}) = \frac{T_c(\text{need}) - RBR_p \times T_{cp} - RBR_s \times T_{cs}}{1 - RBR}
\]

Where

- \(T_c(\text{virgin})\) = critical temperature of the virgin asphalt binder
- \(T_c(\text{need})\) = desired critical temperature of the blended binder
- \(RBR_p\) = Reclaimed Asphalt Binder Ratio for the RAP binder
- \(RBR_s\) = Reclaimed Asphalt Binder Ratio for the RAS binder
- \(T_{cp}\) = critical temperature of the recovered RAP binder
- \(T_{cs}\) = critical temperature of the recovered RAS binder

Testing with Bending Beam Rheometer (BBR) will be conducted at specification temperatures to determine the binder critical cracking temperature. The temperatures of testing depend on the target critical temperature \(T_c(\text{need})\). For a specific combination of virgin binder and RAP/RAS binders, testing is required at two low temperatures, as a minimum. Target critical temperature, \(T_c(\text{need})\), will be determined for both stiffness (S) and relaxation parameter (m value) from BBR testing. The difference between critical temperature based on m value and critical temperature based on stiffness shall not exceed 5°C, as shown in Equation 9. This requirement is based on the recommendation by the FHWA Mixture Expert Task Group, RAP/RAS Task Force. It is believed that a larger difference will reduce the mix resistance to low temperature cracking.

\[
\Delta T_c = -m \text{ value critical temperature - stiffness critical temperature} \leq 5^\circ C
\]

**Note 5:** Conventional practice followed in determination of RAS binder grade as explained in Section 3 of Tier 3 mix design is not applicable for RAS binder due to extremely high stiffness. There is no established protocol for such determination. Soft binder, if properly blended with the RAS binder, delivers a binder with stiffness characteristics in a testable range. If sufficient number of such blends, at different percentages of the RAS and virgin binders, are prepared and tested, then the results could be extrapolated to provide a reliable estimate of the properties of the RAS binder. Three ways of preparing such blends can be considered, as discussed below.

One alternative is to add the virgin binder (or a mix containing virgin binder) to the original RAS mix, at specified percentages, before the extraction process. This way, it is expected that the solvent used in the extraction process would deliver a uniform blend of the two binders.

An easier and faster technique when multiple percentages of RAS binder/Virgin binder are to be blended, is to add the virgin binder to the solution obtained after the extraction process of the RAS. In other words, once extraction of RAS is complete, the virgin binder is added to the resulting solution containing the RAS binder. The blend is fully stirred to dissolve the virgin binder and deliver a uniform blend of virgin and RAS binders in the solution. The amount of virgin binder added to the solution depends on the targeted percentages of RAS binder and virgin binder. For example, the blend could be 40% RAS binder and 60% virgin binder. Once the solution is prepared this way, it will be processed to recover the binder. The recovered binder will be tested to determine the critical temperature. At least, two different percentages of RAS/Virgin combination is needed to establish the relationship between critical temperature and...
percent RAS in the blend. For example, 20%/80% combination, and 40%/60% combination, with the latter number referring to percent of virgin binder in the blend. From these two proportions, along with the critical temperature of the virgin binder, the critical temperature of the RAS binder will be established. It should be noted that the percentages of RAS binder used in blending with the virgin binder are only for the purpose of establishing the RAS binder critical temperature. These percentages are not related to the percent of RAS binder contribution in the asphalt concrete mix.

**Note 6:** Determining $G_{mm}$ of RAS may be a problem and it may be best to use the RAS as a blend with fine aggregate (50:50 blend) and then determine the $G_{mm}$ on the blend. As an alternative, the HMA Producer may request the shingle manufacturer to provide the aggregate $G_{sb}$ and the asphalt binder $G_{b}$ and use these values for the RAS.

**Note 7:** A recommended “best practice” for stockpiling RAS that has been processed (shredded) from full-size manufacturer waste asphalt roofing shingles to the specified 100% passing the 9.5 mm (3/8 inch) sieve is to either blend the processed RAS with a virgin aggregate or store the processed RAS under roof to prevent the processed RAS from conglomerating as a result of storing out in the open under direct sunlight. A recommended “best practice” for blending processed shingles with virgin aggregate is to blend the processed shingles with a fine aggregate as a 50:50 blend before application. This 50:50 blend could then be added as a percentage of the weight of the HMA mixture to obtain the target RBR up to a maximum RBR from RAS of $\leq 0.25$.

Example: RAS binder content: 18%
- Target RBR from RAS: 0.17
- Target binder content of the mixture: 6.5%
- RAS binder needed to deliver target RBR from RAS: $0.17 \times 6.5 = 1.11\%$ of the mixture
- Amount of RAS needed as a percent of the mix: $1.11/18 \times 100 = 6.2\%$

So at 50:50 blend, the RAS-fine aggregate blend will be 12.4% of the weight of the mixture (i.e. 2 X 6.2 = 12.4).

**Note 8:** It is possible that because of high binder content of RAS, the amount of RAS needed to achieve a target RBR will be less than 5%. The plant using RAS in the mix must be properly equipped to measure the amount of RAS fed into the mix accurately even in cases where the RAS amount is very limited.
### TABLE H-3. RECYCLED ASPHALT PAVEMENT OR RECYCLED ASPHALT SHINGLES MIX DESIGN DATA

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<tr>
<th>Sieve Size</th>
<th>RAP or RAS Grading and AC Content</th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 4</th>
<th>No. 5</th>
<th>No. 6</th>
<th>No. 7</th>
<th>No. 8</th>
<th>No. 9</th>
<th>No. 10</th>
<th>Average RAP/RAS Gradation &amp; AC Content</th>
<th>Combined Grading</th>
<th>Proposed JMF</th>
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<td>SR &amp; Section #</td>
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<td>LTS Use Only</td>
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<td>RAP or RAS Stockpile #</td>
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Notes:

Technician

Date